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U.S. NAVY DIVING MANUAL

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RECORD OF CHANGES

CHANGE NUMBER	DATE OF CHANGE	DATE ENTERED	BY WHOM ENTERED

SPECIAL NOTE:

A publication is of value only insofar as it is maintained current and informative. The U.S. Navy Diving Manual (NAVSHIPS 0994–001–9010) must reflect all new developments and current procedures in the diving field.

All individuals and activities engaged in diving are authorized and requested to submit constructive criticism and recommendations for improvement of the manual direct to the:

Officer in Charge
U.S. Navy Experimental Diving Unit
Washington Navy Yard, D.C. 20390

This same procedure is already in effect for submission of originals of activity diving logs (NAVSHIPS 99401 (Rev. 2–67)) and copies of diving accident reports (NAVMED 64201 (Rev. 3–67)).

The Experimental Diving Unit is assigned responsibility for periodic assembly of the field recommendations into proposed numbered changes. These proposed numbered changes will also include information on equipment, techniques, and procedures as they are developed.

The Naval Ship Systems Command is responsible for publication of approved changes to the U.S. Navy Diving Manual.

FOREWORD

NAVY DEPARTMENT
NAVAL SHIP SYSTEMS COMMAND
1 September 1969

The U.S. Navy Diving Manual (NAVSHIPS 0994–001–9010) supersedes the U.S. Navy Diving Manual of 1 July 1963.

The revised Manual has three objectives: (1) to assemble and present all technical information now available; (2) to provide a vehicle for rapid dissemination of new developments; and (3) to authorize the use of specific practices that assist personnel in the field to perform their duties.

This edition of the U.S. Navy Diving Manual represents the greatest revision of this manual in many years. The intent of this manual is to present to the divers of the U.S. Navy the most current information in the field of diving. The format is so designed that, as advances in diving are made, this manual can be kept current by the addition of new information.

E. J. FAHY
Admiral, USN
Commander, Naval Ship Systems Command

PREFACE

This edition of the U.S. Navy Diving Manual represents an extensive revision of and addition to all past editions of the manual. The changes reflected in this manual are the result of a careful appraisal, made from past experience and the expectation of future developments, of all areas in the field of diving.

The U.S. Navy has been involved in diving for approximately six decades. During the first two decades great advances were made in the use of air for deep diving. The second decade showed further advances in deep air diving and also began the era of helium-oxygen diving. In the third decade, the use of helium-oxygen mixtures for deep diving became an operational reality and steadily grew into its present application. The last three decades have seen many changes in diving procedures, both for air and helium-oxygen, as methods and equipment became more refined. It was also during this period that scuba equipment was developed and slowly rose to great prominence in operational diving. The past decade has been one of rapid change in all of these fields, and it has far surpassed in its scope any other comparable period of time in diving.

It is from this past history that this edition of the U.S. Navy Diving Manual has drawn its information, retaining the best that has been achieved in diving and modifying or deleting those areas which have been found to be sources of hazard. It is therefore the purpose of this edition to present the information which is the safest, most accurate, and most current in all areas of present-day diving.

The next decade promises the present advances and innovations in diving equipment and procedures which may overwhelm the imaginations of even the most optimistic of people. Because the U.S. Navy Diving Manual should be the repository for this information as it becomes available, the entire format of this edition has been changed so that, as advances are made, they can rapidly and easily be incorporated into the manual. The physics and physiology of diving will undergo few changes in the future, and the techniques of surface-supplied or scuba diving will not be modified to any great degree. The sections dealing with these subjects are the basis of present-day diving. However, these sections are conspicuously lacking in technical information regarding equipment, because it is apparent that equipment will change radically and rapidly in the future. This technical information is to be found in an appropriate appendix, which at present contains the most current information on the equipment being used in the U.S. Navy. As equipment changes are made, new sections will replace the present ones.

In many instances the equipment descriptions given in the appendixes are taken from the technical manuals for that equipment, and therefore the diving manual is a technical manual on diving equipment as well as a repository of information on diving procedures. When new concepts of diving to great depths using new and advanced techniques are a reality, they will become a part of this manual with appropriate technical appendixes to provide for later changes.

One of the most obvious changes in this edition of the manual is in the diving tables. These tables have been enlarged for easier reading and have been given a new and uniform format. Although the tables have been renumbered for the user's convenience, critical tables have the new number and refer also to the former number. New oxygen depth-time limits have been used to provide for greater safety in the prevention of oxygen poisoning, and the tables reflect these limits. All tables which exceed the new limits are separated as exceptional-exposure tables for use only in extreme cases of operational necessity. With safety as the determining factor, the working- and maximum-depth limits for the different types of equipment have also been modified. Some tables, such as the surface-interval credit tables, which have caused confusion among divers in the past, have been modified to make them less ambiguous.

Several new tables (such as the helium-oxygen decompression tables for mixed-gas scuba, and the minimal recompression oxygen treatment tables) have been added to this edition along with instructions for their use. The oxygen treatment tables are further referenced in many areas of the text for treatment of specific casualties.

The use of oxygen in recompression chambers has long caused concern to many people because of the hazards of fire in an oxygen-rich environment. Therefore, the allowable limits of oxygen concentration in recompression chambers have had to be lowered. This lower concentration in turn has made it necessary to revise the ventilation rules for recompression chambers, and has imposed ventilation rates that are quite high and that can cause hearing loss. The means to avert this hearing loss are given in the text and can easily be achieved. There has also been a revision of the specifications for the purity of air used in diving which allows fewer impurities than before in the interest of safety.

In addition to the appendixes on technical information, there are several appendixes that deal with matters relating to diving; these have been separated from the main text so that they may be kept current or so that new appendices may be added as the horizons of diving expand. One such appendix is a short and concise guide to first aid and covers most of the situations which might confront divers at some time when no medical care is immediately available. Another appendix deals with marine life and its hazards. A further appendix deals with the selection, qualification, and training of personnel and is taken from the latest instructions of the Bureau of Medicine and Surgery and the Bureau of Personnel.

It is hoped that this revision of the U.S. Navy Diving Manual is and will continue to be the safest, most current, and most authoritative volume concerning diving which can possibly be made available to those men in the U.S. Navy who venture beneath the surface of the sea. The credit for the extensive revision of this manual goes to Willis H. Bell II, Lt. (MC), USNR.

EUGENE B. MITCHELL
Captain, U.S. Navy
Supervisor of Diving

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PART 1

GENERAL PRINCIPLES OF DIVING

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SECTION 1.1 INTRODUCTION

1.1.1 THE HISTORY OF DIVING

(1) History gives no record of the date when diving first began or who the first divers may have been, but man's curiosity probably led him into the water and under its surface at a very early stage. Like the native pearl and sponge divers who continue the primitive art, the first divers probably used no equipment at all except perhaps a stone to get them to the bottom more rapidly. Although unaided divers have achieved remarkable depths and durations of dive, it is not likely that the early divers often exceeded 1 or 2 minutes of submergence or 80 to 100 feet of depth.

(2) Written records provide accounts of some ancient diving exploits. Most of these were connected with naval warfare. For example, Xerxes is said to have used combat divers; and over 400 years before Christ, Herodotus told the story of Scyllis, a famous Greek diver who was employed by Xerxes to recover treasure from sunken Persian ships. When the job was done, the conqueror decided to detain Scyllis but the diver went over the side during a storm, threw the whole fleet into confusion by cutting the anchor cables, and then completed his escape by swimming 9 miles to Artemisium. Alexander the Great used divers to destroy the boom defenses of Tyre about 333 B.C. and Aristotle wrote that Alexander himself descended in some sort of a diving bell. Divers were used in at least six naval battles and sieges between 400 B.C. and A.D. 1795. In the early 1800's Spanish warships carried men whose duties were swimming and diving for the fleet, although no breathing appliances were used.

Early Efforts

(3) Several of the ancient accounts indicate that crude means of supplying the diver with air were sometimes used. About A.D. 77 the Roman historian Pliny, in his "Historia Naturalis," referred to military divers who breathed through tubes which were supported at the surface by a float. This was the beginning of the history of surface-supplied diving, with the diver breathing air through a tube led to the surface. This device, similar to today's "snorkel," has appeared in various versions of diving equipment for hundreds of years. While the apparatus is practical for very shallow depths (up to 12 inches), the fact that the diver's lungs remain at atmospheric pressure while his body is exposed to water pressure results in high breathing resistance with an 8- to 12-inch differential and the danger of lung hemorrhage and death at greater depths.

Diving Developments From 1500 to 1800

(4) Interest in diving increased after 1500, and many different rigs were designed. In 1511, a book written by Vegetius in A.D. 375 was published, and a drawing of the diving hood described by him (fig. 1–1) became the first design for diving dress to be found in a printed book. Even before this, the remarkable artist Leonardo da Vinci had sketched diving outfits and hand fins along with submarines and flying machines and other marvels yet to come. In 1524, Vallo designed a leather helmet which was slightly more advanced than that of Vegetius. This one at least provided eyeports, and its leather pipe was reinforced with iron rings and held up by a disk-shaped float. If they were ever built, such rigs could not have been used in water much over the diver's head. In 1680, Giovanni Borelli, an Italian astronomer and mathematician, designed what was probably man's first self-contained recirculating diving apparatus. This equipment, crude by modern standards, nevertheless demonstrated man's desire to be able to dive free of encumbrances and independent of a surface supply of air. The apparatus consisted of a large air bag which fitted over the diver's head. It had a single glass port for vision.

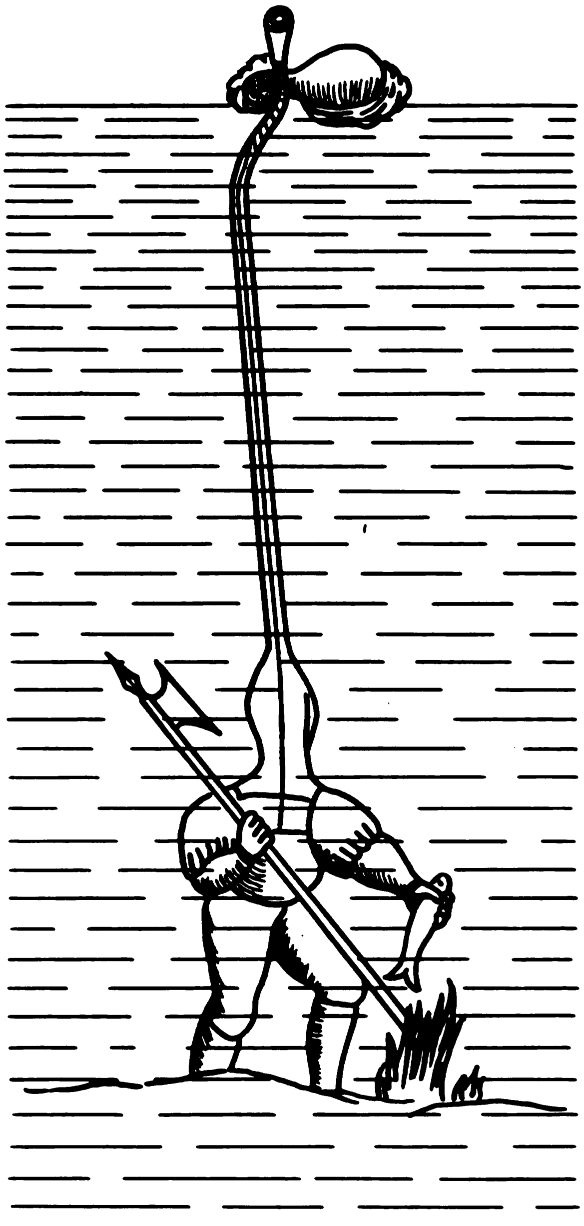

Figure 1-1.—Diving hood of Vegetius.

Air circulated through a tube running outside of the air bag, through a smaller bag intended to trap moisture, and back into the air bag. Borelli believed that water cooling would remove impurities from the exhaled air, making it suitable for rebreathing. To help the diver regulate his displacement in water, the apparatus also had a complicated cylinder and piston arrangement. Although it did not work, this equipment foreshadowed later closed-circuit self-contained underwater breathing apparatus (scuba). Figure 1-2 shows the apparatus as Borelli conceived it.

Figure 1-2.—Borelli's design.

(5) Although little of the equipment designed before 1800 was very practical, the underwater accomplishments of the period were surprising in many ways. A primitive snorkel submarine (propelled by 12 oarsmen) was making regular trips on the Thames around London about the time the Pilgrims landed in America. Diving bells and crude diving helmets were used for work on wrecks submerged in water as deep as 60 feet, and reasonably practical air pumps were developed before the end of the 1700's.

Diving Developments From 1800 to 1900

(6) Diving to increased depths awaited a satisfactory source of compressed air, and various schemes for providing it are mentioned throughout history. About 1800, the first use of a bellows was recorded, and shortly thereafter the first handpumps were used. The advent of compressors started the development of diving as we know it today. With the ability to maintain an air pocket against greater and greater pressures for longer and longer times came the physiological problems of working under pressure. As each prob'em was encountered, its solution was sought through the combined efforts of the scientists and the men willing to try again.

(7) The divers of the 1800's were true adventurers advancing into the unknown. They had no knowledge of how well their equipment would work or against what tests it would be pitted. They had no knowledge of what the pressure, the compressed air, or the combination of the two would do to them. And the harbors of Europe were just as black then as they are now. We owe much to these individualists. It was during this period, in 1819, that Augustus Siebe, a naturalized Englishman, developed his "open" dress, which became the basis of our modern deep-sea outfit. This dress was fed by air pumped to the metal helmet, with exhaust air escaping under a jacket open at the waist. In 1837, Siebe modified his diving dress to the present type with "closed" suit and helmet-mounted exhaust valve.

(8) Development of lightweight equipment for shallow-water use progressed along paths somewhat similar to those followed by the deep-sea equipment. Rapid advancement awaited development of a force pump capable of furnishing air to the diver. The inherent dangers associated with helmets, which were open at the bottom and insecurely balanced on the diver's shoulders, led to the safer and more convenient masks used today.

(9) In 1825, W. H. James, an Englishman, designed a self-contained diving suit, the first to incorporate a supply of *compressed air* (which was contained in an iron reservoir worn about the waist). This equipment aroused little interest and was not considered important at that time. Figure 1-3 shows this suit.

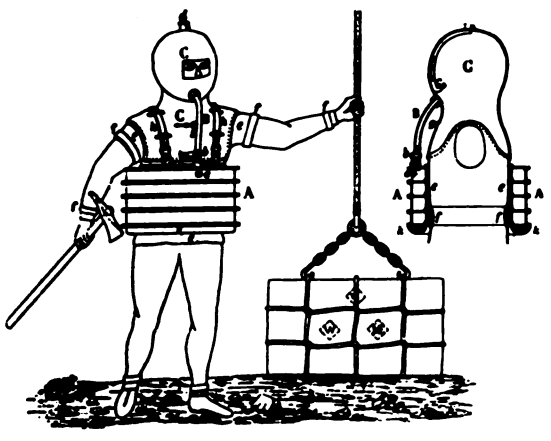

FIGURE 1-3.—James' design.

(10) In 1866, Benoist Rouquayrol of France patented the first satisfactory demand regulator for open-circuit, self-contained underwater breathing apparatus (scuba). This design constituted a milestone in man's efforts to achieve freedom and mobility beneath the sea. The only drawback to the equipment was the lack of a suitable supply of high-pressure air such as is used today. As a result the equipment was developed into a surface-supplied demand apparatus (fig. 1-4).

(11) In 1878, H. A. Fleuss, of the British firm of Siebe-Gorman & Co., designed a workable closed-circuit oxygen rebreathing scuba (fig. 1-5). The unit utilized a solution of caustic potash to remove carbon dioxide from the exhaled gas. In 1902, Fleuss, in collaboration with Sir Robert H. Davis, improved the unit. This apparatus was the prototype of modern submarine escape appliances and became the forerunner of present-day closed-circuit scuba.

(12) One of the most famous divers of the 1800's was Alexander Lambert. His most noted exploit took place when a tunnel being built under the Severn River in England flooded in 1880. Using the forerunner of the oxygen rebreathing apparatus, he went alone down a vertical shaft and far into the tunnel through masses of floating debris. In order to shut an iron door so that the tunnel could be pumped out, he was forced to return to the surface to get a wrecking bar. On his second trip into the blackness, he finished the job. Three years later, the tunnel flooded again and Lambert was hired to repeat the job. He tried to use the same equipment, but this time he was poisoned either by the high oxygen pressure or by carbon dioxide. He barely managed to escape with his life, but he tried again the next day using a surface-supplied rig and was able to complete the job. In 1885, Lambert forced his way through three decks and into the strongroom of a wreck at 162 feet. He recovered nearly half a million dollars in gold, but the job gave him a case of the bends which forced him to retire. (There were as yet no adequate decompression tables; these had to wait for the work of Professor Haldane and his associates in 1907.)

(13) The great contribution to diving made by Dr. J. S. Haldane and his associates in 1907

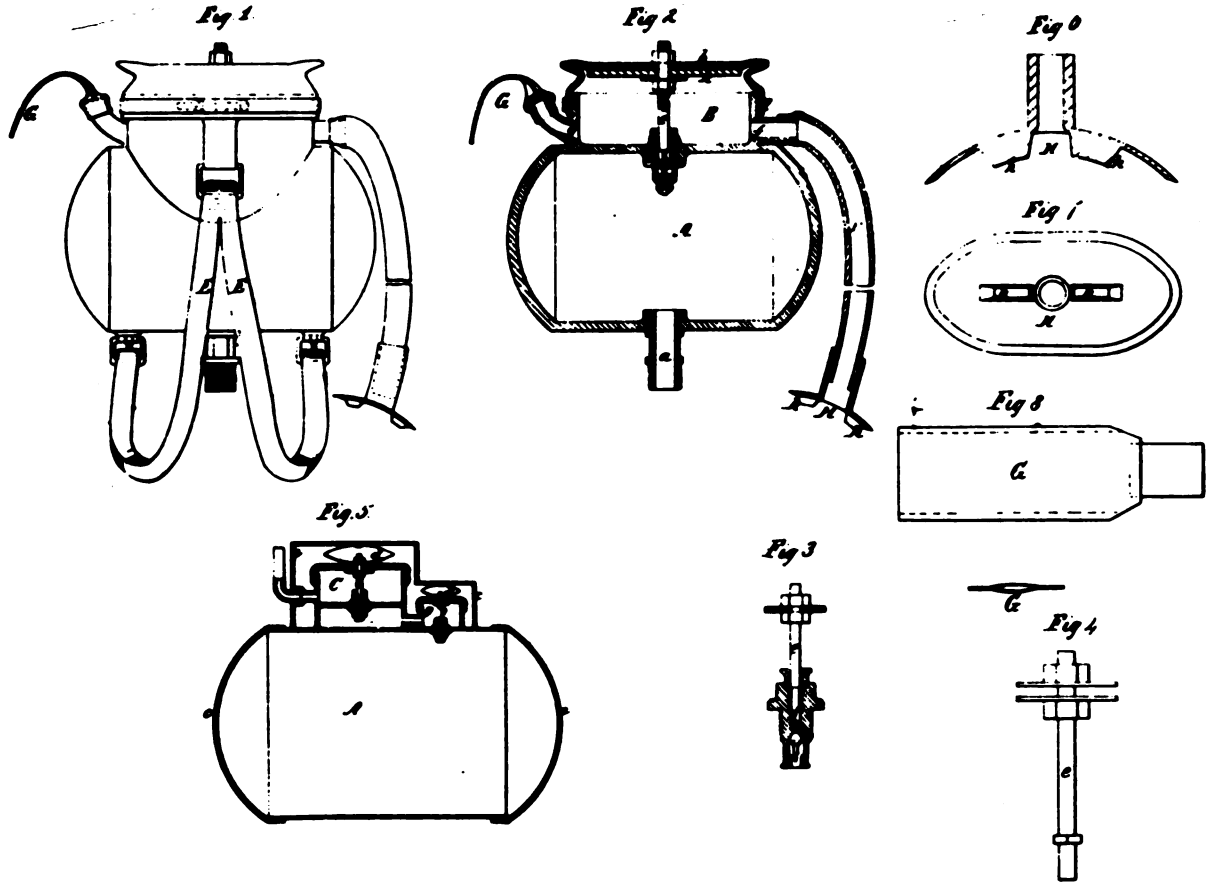

FIGURE 1-4.—Rouquayrol's design.

consisted of putting the problem of decompression on a firm mathematical and physiological basis. They observed that it was possible to bring a diver directly to the surface safely from as great a depth as 33 feet no matter how long his dive had been. In other words, the diver could escape decompression sickness if the tension of dissolved air in all his tissues was no greater than twice the total pressure after his ascent. This observation was used by Dr. Haldane to construct a mathematical model of inert gas behavior in the body and to compute decompression schedules using a stage decompression method. Following experience with deeper and longer dives, it was found that the Haldane 2:1 ratio is not universally safe and it is no longer used. However, a modified Haldane method is still used for calculating decompression schedules and has recently been adapted for electronic computers. The method of stage decompression has long been accepted as the most practical, most time-saving, and safest method of bringing a diver up from a dive too deep or too long for immediate surfacing.

Diving Developments Since 1900

(14) It has been established that oxygen in high concentration and under high pressure becomes toxic and that nitrogen under high pressure produces a narcotic effect. To overcome the physiological effects of these two gases it was necessary to produce a new artificial atmosphere having a variable oxygen percentage, and to reduce the narcotic effect of nitrogen. As early as 1921, it was suggested that a lighter inert gas could beneficially be substituted for nitrogen in the breathing medium of the deep-sea diver.

(15) In 1925, a French naval officer developed a self-contained unit with cylinders of compressed air rather than oxygen. The apparatus was basically an open-circuit scuba. However,

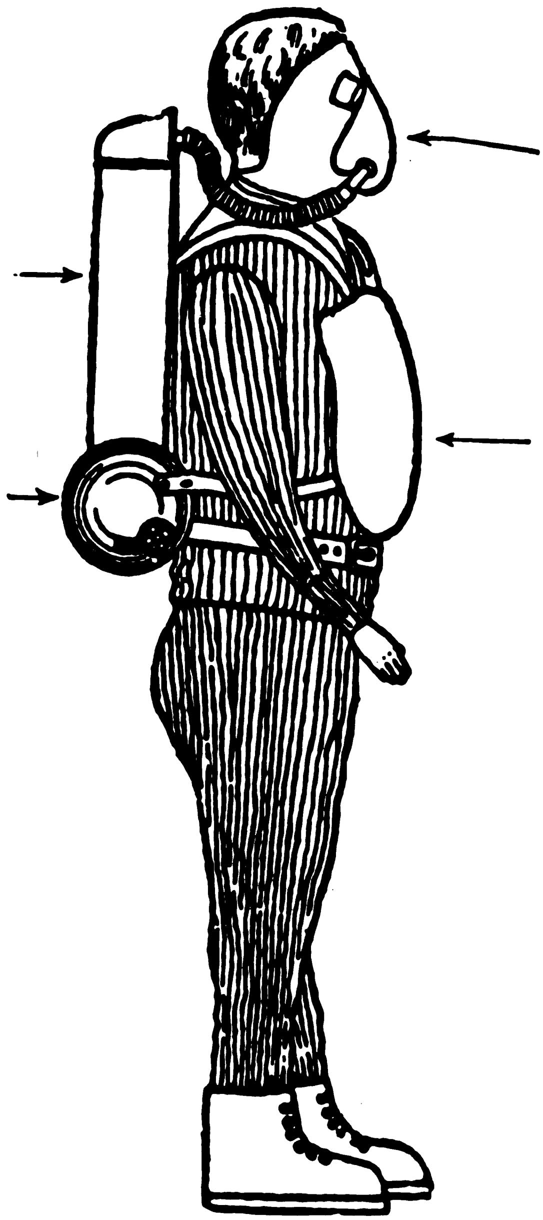

FIGURE 1-5.—Fleuss' design.

the unit was not completely satisfactory because the flow of air was regulated manually by the diver. This feature resulted in excessive use of the limited air supply.

In 1943, another French naval officer introduced the Cousteau-Gagnan *Aqua-Lung*. This device also used cylinders of compressed air but was equipped with a demand regulator which adjusted the air pressure automatically and supplied air to the diver as needed. Basically this equipment was identical to Rouquayrol's except for the fact that it had a much larger air supply. The cylinders held high-pressure air (2,000 psi) rather than the low-pressure air (500 psi) available in Rouquayrol's day. The greater air supply gave the diver a much longer time beneath the surface.

(16) World War II provided the incentive necessary for rapid strides in the development of closed-circuit scuba. In September 1941, Italian Navy scuba divers very dramatically demonstrated the importance and potential military value of scuba when they carried out a successful attack against a British tanker at Gibraltar. This attack and others that followed did much to give the U.S. and British Navies an interest in developing scuba and training scuba divers.

(17) Since 1943, several individuals and corporations have developed demand regulators based on Rouquayrol's principles. With minor variations, this type of open-circuit equipment is in wide use today.

Diving in the U.S. Navy

(18) Not much is actually known about the beginning of diving in the U.S. Navy. Although good work evidently was done at shallow depths in the early days, very little was accomplished in deep diving. Largely as a result of the efforts of Chief Gunner George D. Stillson, an active development program was started in 1912 to check the practicability of Haldane's stage method of decompression and to improve the standard Navy diving gear to permit deeper dives. Extensive tests were conducted in diving tanks ashore and later from the U.S.S. *Walke* in Long Island Sound. The value of the work was evident in the salvage operations on the submarine U.S.S. *F-4* off Honolulu in 1915. On that job, divers descended to 304 feet—a depth which is probably a record for useful diving in the standard rig with air as the breathing medium.

(19) After the *Walke* tests, a diving manual was issued and the Navy Diving and Salvage School was established at the Naval Torpedo Station at Newport, R.I. This school was discontinued when the United States entered World War I. Personnel and graduates of the school formed a nucleus for the oversea salvage division, which was established as a unit of the U.S. Naval Forces abroad. Throughout U.S.

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participation in the war, these divers rendered valuable service in salvage operations along the French coast.

(20) The need for further development in diving was strongly emphasized by two tragic accidents that occurred in the midtwenties. On 25 September 1925, the U.S.S. *S-51* was rammed by the steamship *City of Rome* and sank in 132 feet of water off Block Island. Only three of the crew survived. At the time, only 20 Navy divers were qualified to dive deeper than 90 feet, and only six civilian divers on the east coast of the United States were willing to dive in 132 feet of water. Salvage operations commenced on 26 September 1925 but were interrupted by winter storms. The *S-51* was finally raised on 5 July 1926 and towed to the U.S. Naval Shipyard, Portsmouth, N.H. The many difficulties encountered were made more serious by the fact that so few divers had been trained to work at such a depth.

(21) On 17 December 1927, the Coast Guard Cutter *Paulding* collided with the U.S.S. *S-4* (SS-109) just to the south of the extreme tip of Cape Cod. The *S-4* immediately sank in 102 feet of water with all personnel on board. Divers reported signs of life in the boat 22 hours after the collision. The salvage vessel *Falcon* succeeded in ventilating the compartment but bad weather forced her to cease operations. Rescue attempts were terminated on 24 December 1927. This accident underlined the need for some means of getting personnel out of a disabled submarine. On 27 December 1927, the salvage phase of the operation began. Again the work was hampered by a shortage of divers qualified to work at the depth involved. Only 24 were available. The *S-4* was raised on 17 March 1928 by divers working from the U.S.S. *Falcon*.

(22) Even before the loss of these submarines, there was concern over the possibility that rescue and salvage operations would be needed at great depths. Divers could not retain their mental clarity and effectiveness when breathing air during deep dives, so some other breathing medium was needed. In late 1924, the Navy's Bureau of Construction and Repair (forerunner of the Bureau of Ships) joined with the Bureau of Mines in investigating the use of helium-oxygen mixtures. The preliminary work was conducted at the Bureau of Mines Experimental Station in Pittsburgh, Pa.

(23) Experiments on animals, later verified by studies with human subjects, clearly showed that helium-oxygen mixtures offered great advantages over air for deep dives. There were no undesirable mental effects, and there was reason to expect advantages in decompression time. In the early part of 1927, the experiment on the use of helium-oxygen had reached the stage where it was desirable to transfer the Experimental Diving Unit from the Bureau of Mines to the Navy Yard, Washington, D.C., as a permanent activity under the Bureau of Construction and Repair (which became the Bureau of Ships and is now Naval Ship Systems Command). The Unit's mission was to continue the investigation of helium-oxygen and to conduct other developmental work in diving practices and equipment. Research done by the Unit developed the original preliminary ideas into effective and economical methods of utilizing the superior qualities of helium-oxygen mixtures. Test work in pressure tanks plus practical experience in salvage operations (such as on the U.S.S. *Squalus* in 1939) culminated in an accurate set of gas mixtures and decompression tables which have been used (with some modification) to depths as great as 500 feet in the open sea. The Experimental Diving Unit has functioned continuously from its inception to the present time.

(24) The Naval School, Diving and Salvage, was reestablished in 1926–27 at the Washington Navy Yard. This location was chosen with the view that its proximity to the Experimental Diving Unit would permit expeditious application of approved experimental findings to the standard training curriculum. The school is operated under the cognizance of the Bureau of Naval Personnel. The facilities, completed in 1943 (figs. 1–6, 1–8, and 1–10), include two pressure tanks capable of withstanding 350 pounds' working pressure and 525 pounds' test pressure. Each pressure tank is directly connected to a recompression chamber. Two open tanks are also used for training purposes.

(25) The Experimental Diving Unit is equipped with two pressure tanks and recompression chambers which are duplicates of those

FIGURE 1–6.—U.S. Navy Experimental Diving Unit and Naval School, Diving and Salvage.

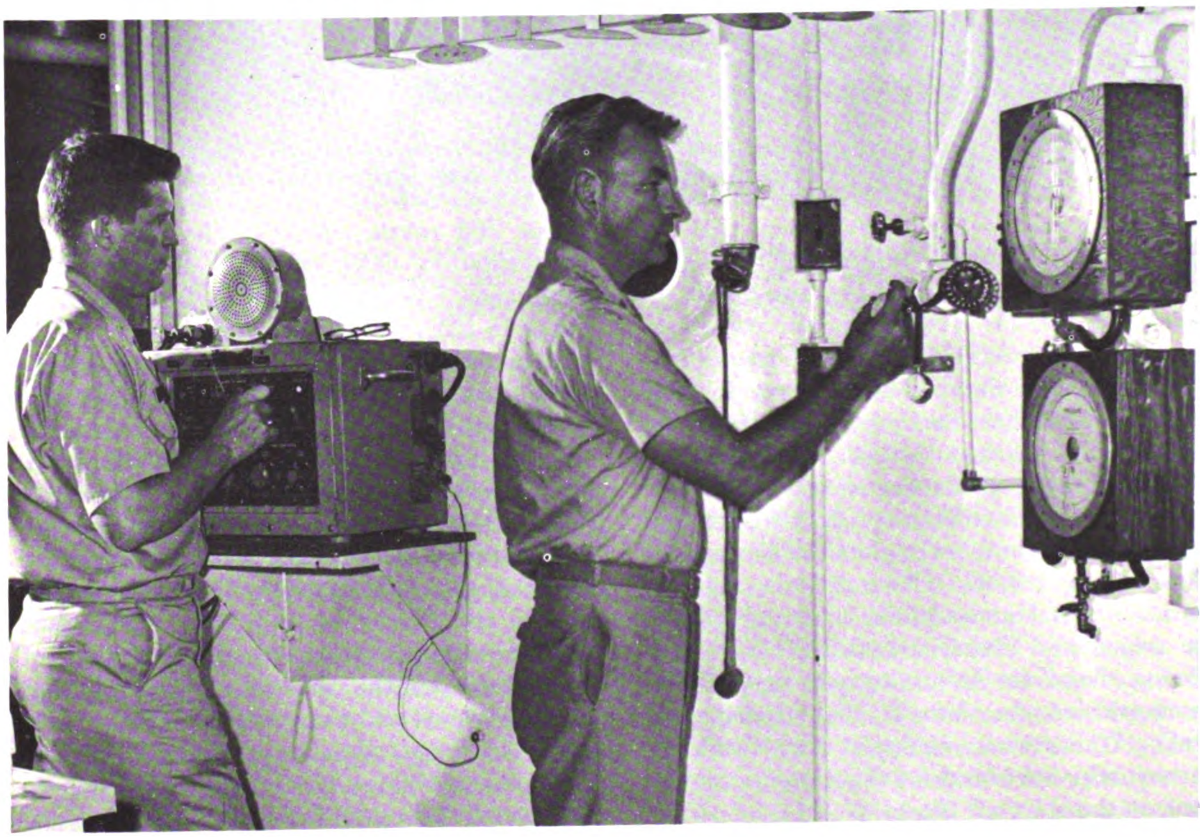

FIGURE 1–7.—Pressure tank, Experimental Diving Unit. The two wet-pressure tanks in the Deep-Sea Diving School are used for training in deep diving; those in the Experimental Diving Unit are employed in the testing of decompression tables and for experimental dives.

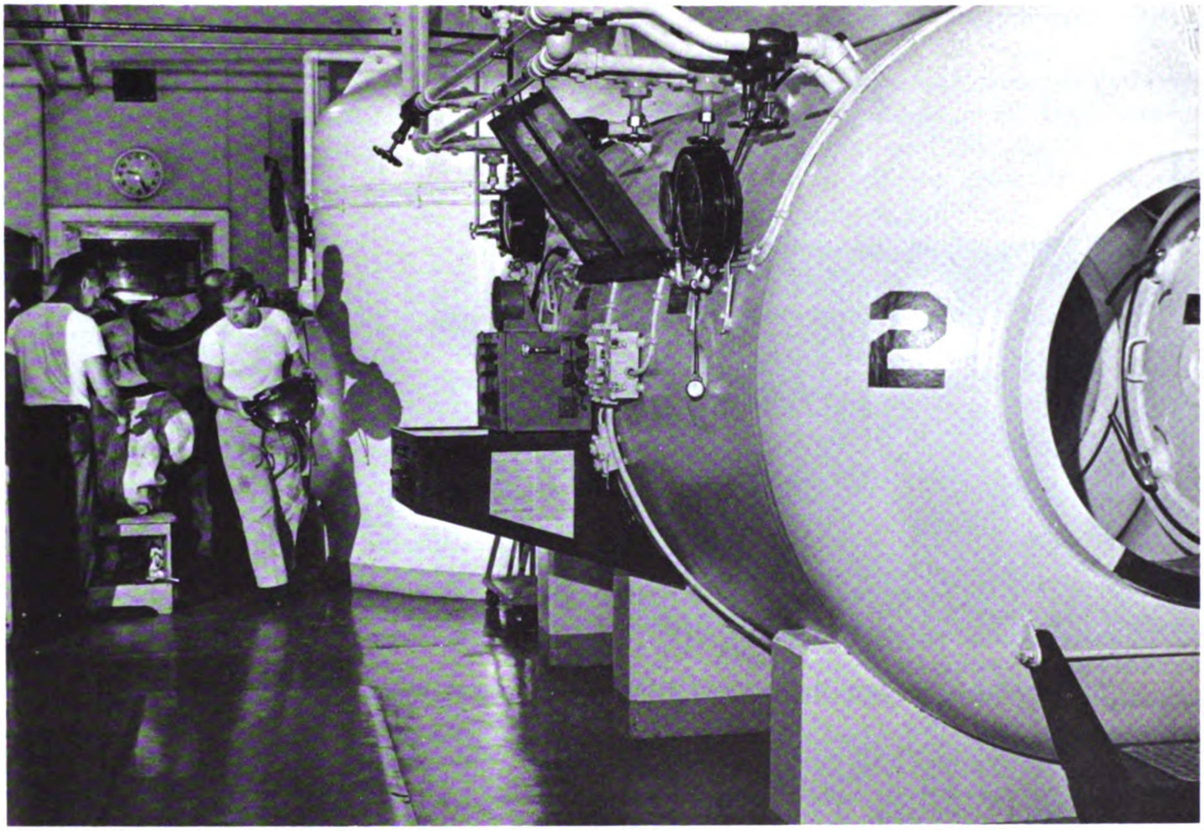

FIGURE 1–8.—"Igloo" and recompression chamber, Deep-Sea Diving School. Above each pressure tank is an access chamber (igloo), and a recompression chamber (right) is connected to the igloo.

installed in the Diving School except that the pressure tanks have been refurbished to provide the capability of a working pressure of 445 psi and a test pressure of 668 psi. The complexes have also been provided with a life-support system which can maintain a safe and comfortable artificial atmosphere for long periods of time by the removal of carbon dioxide and other atmospheric contaminants and by effective control of temperature and humidity. Instrumentation continuously monitors the chamber atmosphere (figs. 1–7 and 1–9). There are also modern workshops and an excellent laboratory. Both the school and Experimental Unit have gas-mixing rooms for helium-oxygen supply. The recompression chambers at the Experimental Diving Unit are also equipped for altitude experimental work; much of this latter work was done at the start of World War II.

(26) The submarine disasters of 1925 and 1927 spurred not only further progress in diving but also greater development in submarine escape and rescue methods. The years of experimentation which had been devoted to the technique of helium-oxygen diving paid dividends in 1939. On 23 May of that year, U.S.S. *Squalus*, a submarine of the newest type, submerged with its main induction valve open and sank in 243 feet of water off the Isle of Shoals in the North Atlantic. On 24 May 1939, the U.S.S. *Falcon*, veteran of the *S–51* and *S–4* jobs, arrived with a rescue chamber. The chamber was first attached to the forward hatch of the *Squalus*, and 33 survivors were safely brought aboard the *Falcon* in four trips. The rescue chamber was then attached to the after hatch of the *Squalus*, but the sad word was reported that all was flooded and there were no signs of life.

(27) Salvage work began immediately on the *Squalus*. This work resulted in the first experimental field application of helium-oxygen diving. The divers were able to think clearly and work efficiently when breathing helium-oxygen mixtures at the 243-foot depth. Surface decom-

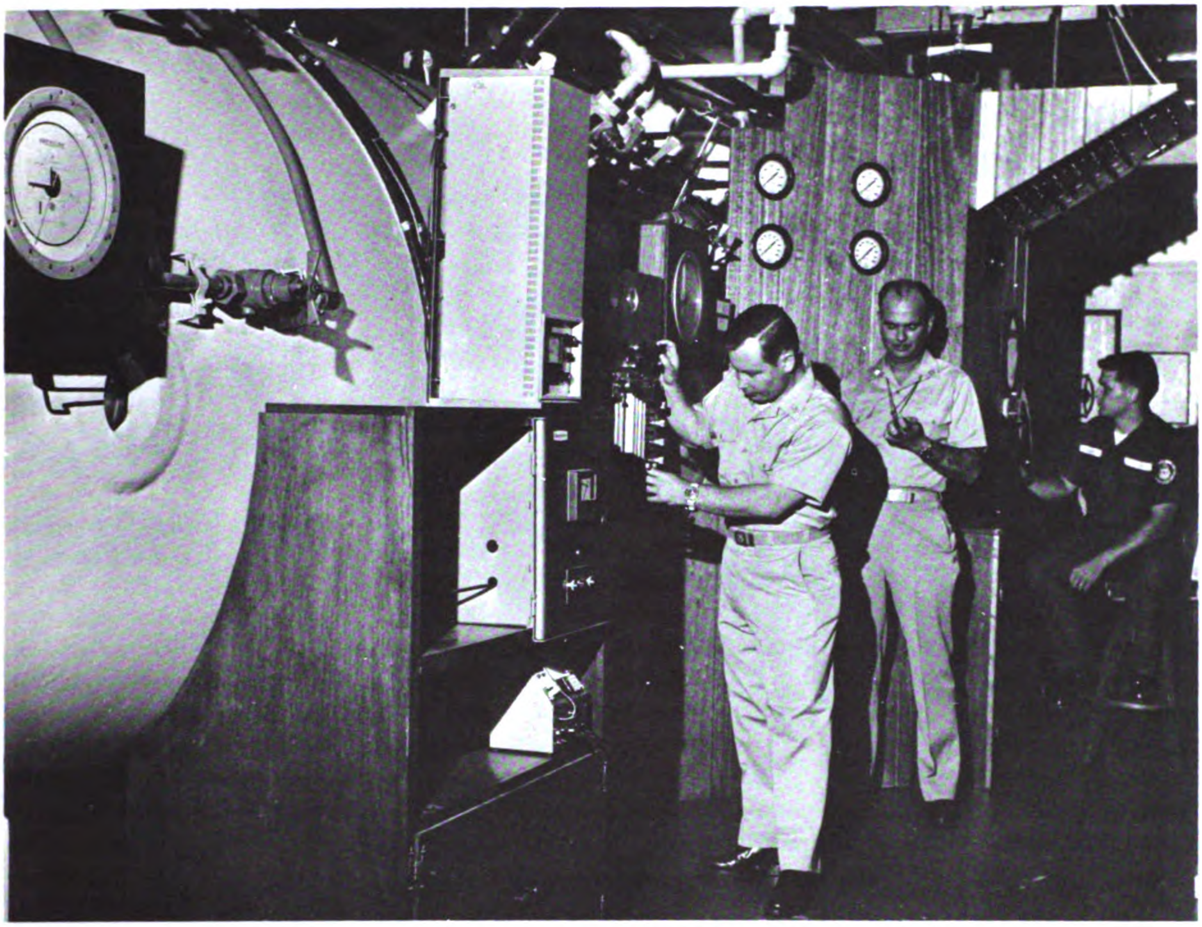

FIGURE 1–9.—Recompression chamber and controls, Experimental Diving Unit. The unit's recompression chambers are used for equipment evaluations and experimental "dry dives" as well as for treating decompression sickness. They are equipped with special instruments for both depth and high-altitude pressures.

pression with oxygen was also used successfully. On 13 September 1939, the *Squalus* was towed into port, following months of heroic salvage work. Had air alone been available for a breathing medium, it is doubtful that the demanding job could have been accomplished. The *Squalus*, rechristened the *Sailfish*, was restored to service and contributed to the Allied victory in World War II.

(28) With the expansion of the U.S. Navy to include ships specifically designed for ship salvage work and because of the requirements of diving under wartime conditions, it was necessary to increase the facilities for the training of divers. About the time this expansion was under consideration, a fire broke out in the U.S.S. *Lafayette* (formerly the French liner *Normandie*) while it was docked at pier 88, North (Hudson) River, in New York. The ship capsized while the fire was being extinguished. The righting of the liner provided an excellent opportunity to establish a diving school where practical experience for ship salvage personnel could be obtained. In addition to the experience that could be obtained on the U.S.S. *Lafayette*, the large number of other diving jobs in the harbor increased the advantages of the location. The Naval Training School (Salvage) was established on a permanent basis in September 1942 to provide for the increased need for divers. During 1946, the school, as the U.S. Naval School, Salvage, was transferred from pier 88, New York, to Bayonne N.J. This school was authorized to train and designate salvage divers. In the summer of 1957, the school was disestablished at Bayonne, and the courses for

FIGURE 1-10.—Students learn diving techniques in Deep-Sea Diving School open tanks before going on to river diving and pressure tanks.

salvage divers and salvage diving officers were moved to the school at Washington.

(29) In addition to the Naval School, Diving and Salvage, there are diving activities within the fleet and at various naval shipyards which are authorized to train and designate divers second class.

(30) During and after World War II, the Experimental Diving Unit continued the improvement of helium-oxygen equipment and techniques. Dives as deep as 561 feet were made using helium-oxygen gear in wet pressure tanks. Research in other aspects of diving also continued. One notable advancement was the development of tables for surface decompression after air dives, using oxygen to appreciably shorten the decompression time. The Unit's work in recent years has reflected the growing importance of diving with self-contained underwater breathing apparatus (scuba). Many different types of this equipment have been developed and tested, and numerous physiological studies concerning the unusual problems of self-contained diving have been conducted.

(31) The military potential of self-contained diving was demonstrated conclusively during World War II. In 1947, the first submersible operations platoon was organized in Underwater Demolition Team 2 for the purpose of applying scuba to UDT (Underwater Demolition Team) operations. Men assigned to the platoon were trained in such skills as underwater reconnaissance, underwater long-distance swimming, and the application of these and other techniques to offensive and defensive operations. At the present time, self-contained

diving finds many applications in the work of Underwater Demolition Teams and Explosive Ordnance Disposal Groups; it also has proved advantageous for various other underwater jobs. In 1954, the U.S. Naval School, Underwater Swimmers, was established at the U.S. Naval Station in Key West, Fla., specifically for the training of scuba divers.

The New Era

(32) The U.S. Navy has recently embarked upon a new era in deep-sea diving. Preceded by the Navy Leased Advanced Diving System IV, a new diving system has been developed, constructed, and tested for use by the fleet. This system (called the Deep Diving System Mk I) was conceived as a means to place divers at depths as great as 850 feet for extended periods of time. Its development was brought about by the need for a deep diving system capable of providing a safe working environment for dives to the maximum depths of the Continental Shelf.

(33) Recent experience in unsaturated (bottom times of less than 12 hours) and saturated (bottom times in excess of 12 hours) deep diving techniques as practiced at the Navy Experimental Diving Unit has proved that maximum control of hazards can be obtained by providing the diver with submersible and surface pressure chambers, specially designed breathing equipment, heated suits, and constantly controlled and monitored life-support systems.

(34) The deep diving system developed to meet these requirements has been designated the Mk I Deep Dive System (DDS). It is capable of supporting two two-man diving teams alternately diving to a maximum depth of 850 feet with a bottom work period of four hours for each team. This diving sequence can be repeated as required to complete salvage or rescue operations within the 14-day mission time plus decompression time.

(35) A second system, similar to the Mk I system, has also been developed and is under construction by the U.S. Navy. It is designated the Mk II Deep Dive System and is capable of supporting two four-man diving teams. Its capability is greatly extended for saturation diving techniques similar to those used in the SEALAB program. Operational procedures are similar to the Mk I system, a feature which will greatly facilitate the training of personnel in the use of these systems.

(36) In 1967 and 1968, personnel of the Navy Experimental Diving Unit, in cooperation with personnel from the SEALAB program, carried out extensive tests in the techniques of saturation diving. During these experiments, divers were subjected to simulated saturation depths of a maximum of 825 feet for extended periods of time without apparent adverse effects. During one of these dives, two divers made an excursion dive from their 825-foot saturation depth to 1,025 feet without incident. This recent body of experience has shown that man can be exposed to great pressures, the limits of which remain undefined, without hazard if he is supplied the necessary equipment and technical knowledge. The Mk I and Mk II Deep Dive Systems have been developed to provide this vastly expanded diving capability to the fleet.

1.1.2 TYPES OF DIVING EQUIPMENT AND THEIR USES

General

(1) To a considerable extent, diving has been thought of primarily in terms of depth—shallow water and deep sea. These two terms have been used so frequently that the whole subject of diving has unconsciously become divided into these two categories. Shallow-water diving has come to imply diving to less than 36 feet and deep-sea diving to depths in excess of 36 feet. This distinction has led many individuals erroneously to consider depth to be of primary importance in diving. However, diving must be associated with accomplishing particular tasks under varying conditions. In ordinary diving (other than diving to extreme depths, where hazards are increased), the type of work to be undertaken, location of the work, the extent of the operations, and the climatic conditions, in addition to the depth, should be the determining factors in deciding upon the method, the personnel, and type of equipment to be used for accomplishing the task.

Self-Contained vs. Surface-Supplied Diving

(2) In recent years the use of self-contained diving apparatus (scuba) has gained increasing importance and value to the Navy. Its superiority to surface-supplied equipment is unquestioned for certain types of diving operations, but it is unlikely that surface-supplied diving will lose its prominence in the Navy. Because of the inherent limitations of scuba, surface-supplied equipment remains superior for dives of long duration, for those to great depths, and for dives requiring hard work.

(3) The Navy employs several different types of diving equipment, depending upon the circumstances and the job to be done. Details concerning diving equipment will be found in Chapter 2, "Surface-Supplied Diving," and Chapter 3, "Self-Contained Diving."

1.1.3 APPLICATIONS OF DIVING

(1) Most of the developments in diving stemmed from the need to accomplish some specific kind of underwater work. As diving itself progressed, and as new tools and techniques were developed, more and more types of underwater activity became possible. Today, men dive for purposes which range from warfare to pure sport. Some of the more important naval applications of diving are described below.

Ship Salvage

(2) Ship salvage work is one of the most important applications of diving in the Navy today. Present-day ship salvage work is a specialized job which can put to use most types of diving equipment and almost every special skill a diver can have. It can require the use of pneumatic tools, explosives, underwater cutting and welding, and many other techniques, as well as the specific know-how of salvage work itself. The underwater phases of ship salvage usually consist of repairing damaged ships, raising sunken ships, refloating grounded ships, and clearing harbors. The Navy has several types of salvage ships, most of which carry divers and several types of diving equipment. These ships are capable of performing all varieties of ship salvage work from simple underwater repairs to major refloating operations.

Submarine Rescue

(3) Most submarine squadrons have a submarine rescue ship (ASR) which is fully equipped and ready to aid a submarine in distress. Each ship carries a submarine rescue chamber and is prepared to conduct all types of diving. The ASR's were previously the only ships in the Navy equipped for helium-oxygen diving. The role of diving in submarine rescue can be of vital importance. Although the messenger buoy released by a sunken submarine is intended to carry the chamber-downhaul cable to the surface, unusual conditions may require a diver to rig the cable or free it from obstruction. Difficulties with the rescue chamber itself could require diving, and in some cases it might be necessary for a diver to attach air hoses to the submarine. In addition to conducting repeated drills and periodic simulated rescue exercises to maintain a high degree of training and readiness, the ASR's provide many useful services, diving and other, to their squadrons and the fleet.

Search and Recovery

(4) Many objects, including practice torpedoes, often must be located and recovered by an underwater search. All types of underwater search are tedious and time consuming, unless the location is accurately known and the underwater visibility is exceptionally good. Although drags, sonar gear, or electromagnetic detection equipment are often used to provide a more effective and efficient means of search than does diving, a diver must usually verify any contacts. Where this equipment cannot be used, searching becomes wholly the diver's job. Also, once the object is located a diver usually must rig lifting lines or some other means to raise it.

Inspection and Repairs

(5) All types of diving equipment can be utilized for inspections and repairs. Diving inspections are usually conducted more easily and efficiently with scuba equipment because of the mobility it supplies to the diver. Inspections usually made by Navy divers are ship-bottom inspections which may be required for such reasons as suspected damage, leakage, routine checks of sonar equipment, and sea-valve troubles. (In time of war, bottom inspections

would also include search for underwater ordnance.) Much repair work on underwater parts of floating equipment can be accomplished by the use of divers, thus eliminating the expense and loss of time entailed by drydocking. Repair work is ordinarily minor, although some major repairs have been effected in emergencies. Ship repair work often accomplished by divers includes changing propellers, replacing zincs, patching minor damage, clearing fouled propellers, straightening bent propeller blades, blanking off sea chests, and repairing minor damage to sonar equipment. Divers are also called upon to repair pipelines, tunnels, bridges, cable moorings, piers, and other structures.

Construction

(6) Navy divers are not usually employed in construction work, but much work is accomplished by divers in the building of tunnels, bridges, caissons, and occasionally wharves and piers.

Tactical Diving

(7) Although history indicates that divers were used for warfare in very early times, tactical diving is comparatively new to modern military operations. Tactical diving was developed into a very potent weapon of both offense and defense during World War II. Developments in self-contained underwater breathing apparatus made this military application practicable.

(8) Many of the characteristic operations of Underwater Demolition Teams can be conducted without diving equipment, but the ability to approach enemy beaches without surfacing is of great advantage. Bottom reconnaissance or the location and demolition of underwater obstacles are primarily diving tasks. The development of surface detection equipment may make it impossible to use surface swimmers because of the danger to the men and the probability of giving advance warning of a projected invasion. Detection is less probable with self-contained equipment, and the swimmers retain the advantage of freedom and the ability to make direct observations. Direct attacks on ships require self-contained equipment for undetected approach and safe departure as well as for underwater work on the ships. Landing parties with the ability to approach submerged can make successful raids upon even closely guarded installations.

(9) Adequate *defense* may also require self-contained diving. Divers may prove to be the only effective defense against individual attacks on shipping. Although direct interception of swimmers and underwater hand-to-hand combat are not very probable, routine ship-bottom searches may be essential. The slow progress of a diver encumbered with surface connections makes self-contained apparatus very desirable for such jobs. Locating and inactivating mines presents similar problems. If the type of mine or its position precludes working from the surface, diving is the only alternative. The limitations upon speed and mobility imposed by surface connections may dictate the use of self-contained equipment.

(10) In wartime situations where proximity to the enemy would expose a surface vessel to undue danger, self-contained diving may provide the only way to accomplish a variety of underwater jobs. The many possible tactical applications of diving, especially with self-contained gear, include even operations undertaken by land forces. Destruction or construction of bridges are examples.

1.1.4 PHYSICS AND PHYSIOLOGY

(1) The forces that act upon a diver under water are explained by the science of *physics*, which deals with the properties and behavior of matter. The effects of these forces on the body are explained by *physiology*, which is concerned with the body's functions and its response to various conditions. Both of these sciences developed within fairly recent times. Archimedes explained buoyancy many centuries ago, but little was known about pressure and its effects until Robert Boyle did his experiments in the 1600's. Practically nothing was known about the composition of air or even the existence and importance of oxygen until Priestley's work in the late 1700's. Understanding of the body's vital functions, such as breathing and the circulation of blood, developed even more slowly. Without such knowledge, it is not surprising that progress in diving was at a standstill for thousands of years and that even brilliant men

designed rigs which could not possibly have worked.

(2) The first real progress in diving came about mainly through increased knowledge in physics and advancements in invention and manufacturing. For example, until workable air pumps and hoses became available and were applied to diving, divers could not go beyond very shallow depths. This development did not occur until around 1800, about the time steam engines began to be used extensively. Some of the most serious problems of diving naturally did not arise at all until progress made it possible for man to be exposed to high pressures. Decompression sickness was unheard of until caissons were put into use after 1840. In the years that followed, scores of men were killed or maimed by decompression sickness until the 1870's, when the great French physiologist, Paul Bert, experimented with animals and applied existing knowledge to explain this condition. Improvements in decompression methods and the beginnings of recompression treatment followed his work, but needless suffering and deaths continued until investigators like Haldane put the matter on a firmer basis in the early years of our own century. Much the same sequence of events also took place with nitrogen narcosis, oxygen poisoning, and other diving problems.

(3) Present-day divers have no cause to look down on their predecessors for their ignorance. The average person today, although he enjoys all the benefits of science, knows little more about physics and physiology than his ancestors did. Divers still face many problems which are unsolved because of a lack of knowledge. The least a diver can do is to learn the essentials of what is known in physics and physiology as they apply to diving.

SECTION 1.2 UNDERWATER PHYSICS

1.2.1 INTRODUCTION

Basic Concepts

(1) Man seldom pays much attention to the natural surroundings or atmospheric conditions under which he lives. He may notice the weather every day, but he hardly thinks of the fact that the air he breathes is under a certain pressure and has a constant composition. When man tries to leave his normal atmospheric environment by going to high altitudes or by descending into the ocean, he soon discovers how important his surroundings are. He learns that he can exist in other environments only to the extent that his body can make adjustments or that his equipment can maintain some semblance of normal conditions.

(2) To understand diving and its effects on the human body, it is necessary to know something about the *physics* of diving. *Physics* is the science which deals with the properties of *matter* and the way matter behaves under varying conditions.

(3) *Matter* is any thing which occupies space and has weight. Matter exists in three states: solids, which have a definite volume and shape; liquids, which have a definite volume but which conform to the shape of their containers; and gases, which have neither a definite volume nor a definite shape. All matter exists in one of these states. Any specific kind of matter may exist in more than one state, depending on the temperature and pressure. For example, water may also exist as ice and steam. In diving, liquids and gases are of primary interest.

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(1) All gases have weight and occupy space. Compared to liquids, gases are very light and compressible. They have no definite volume or shape.

Specific Gases

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under pressure, than air. This gas is colorless, odorless, tasteless, and inert. It is exceptionally light, nontoxic, and nonexplosive; and it conducts heat much more rapidly than air.

(6) *Hydrogen* (H) is colorless, odorless, and tasteless. It combines with oxygen in a ratio of 2:1 to form water. This combination takes place as a rapid and hot combustion, and mixtures of hydrogen and oxygen at or near the proper proportions are violently explosive. Hydrogen and oxygen can be mixed in proper portions to form a satisfactory breathing medium for deep diving, but such mixtures have no important advantage over helium-oxygen mixtures and are technically more difficult to use. Since helium is readily available in the United States, hydrogen has never been used for diving by the U.S. Navy.

(7) In addition to the above gases, which are used alone or in combination to form breathing media, there are two harmful gases with which divers should be familiar. One of these gases is *carbon dioxide* (CO_2). This gas is colorless, odorless, and tasteless in the percentages likely to be encountered by divers; however, it has an acid taste and odor in high concentrations. It is a combination of two parts oxygen and one part carbon and is produced by burning organic material and by the normal oxidation of food in the body. If a carbon dioxide concentration builds up in a diver's breathing medium, harmful effects result (*carbon dioxide excess*).

(8) The other important harmful gas is *carbon monoxide* (CO) which is colorless, odorless, tasteless, and highly poisonous. Carbon monoxide is produced by incomplete combustion of carbon-bearing materials due to an insufficient oxygen supply. Each molecule of this gas has only one atom of oxygen for one of carbon, instead of two oxygen atoms as does carbon dioxide. Carbon monoxide is found in dangerous concentrations in engine exhausts and in closed compartments where paint or stores have been deteriorating. If it contaminates a diver's air supply, serious consequences can result (*carbon monoxide poisoning*).

Composition of Air

(9) Air is a simple mixture (not a chemical combination) of nitrogen and oxygen with small amounts of argon and carbon dioxide and traces of certain other gases. Air also contains water vapor which varies in amount according to the weather conditions (see table 1-1). The proportions of the main components of dry air are as follows:

Component	Percent by volume
Nitrogen	78.084
Argon (inert)	.934
Oxygen	20.946
Carbon dioxide	.033
Rare gases (neon, helium, krypton, hydrogen, xenon, radon, carbon monoxide)	.003

TABLE 1-1.—*Weight in grains of the aqueous vapor contained in a cubic foot of saturated air*

Temp, °F	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
−10	0.285	0.270	07257	0.243	0.231	0.218	0.207	0.196	0.184	0.174
−0	.481	.457	.434	.411	.389	.370	.350	.332	.316	.300
+0	.481	.505	.529	.554	.582	.610	.639	.671	.704	.739
10	.776	.816	.856	.898	.941	.985	1.032	1.079	1.128	1.181
20	1.235	1.294	1.355	1.418	1.483	1.551	1.623	1.697	1.773	1.853
30	1.935	2.022	2.113	2.194	2.279	2.366	2.457	2.550	2.646	2.746
40	2.849	2.953	3.064	3.177	3.294	3.414	3.539	3.667	3.800	3.936
50	4.076	4.222	4.372	4.526	4.685	4.849	5.018	5.191	5.370	5.555
60	5.745	5.941	6.142	6.349	6.563	6.782	7.009	7.241	7.480	7.726
70	7.980	8.240	8.508	8.782	9.066	9.356	9.655	9.962	10.277	10.601
80	10.934	11.275	11.626	11.987	12.356	12.796	13.127	13.526	13.937	14.359
90	14.790	15.234	15.689	16.155	16.634	17.124	17.626	18.142	18.671	19.212
100	19.766	20.335	20.917	21.514	22.125	22.750	23.392	24.048	24.720	25.408
110	26.112	26.832	27.570	28.325	29.096	29.887	-------	-------	-------	-------

(10) Two other inert gases have been used to some degree in experimental diving. These are argon and neon. Both are denser than helium; they therefore offer no advantage over helium in deep diving, because their breathing resistance is prohibitive. Studies of their possible narcotic effects have been made, but their effects under high pressures on humans remain largely unknown. In some cases, they have been used in various mixtures with helium and oxygen in an attempt to conquer the poor intelligibility of helium speech. Some studies have been made to ascertain whether they might provide an advantage to nitrogen and helium in decompression, but the results thus far have been inconclusive.

1.2.4 PRESSURE

(1) *Pressure* is the amount of force per unit area. Force is any push or pull that tends to produce motion. It is commonly expressed in pounds. Area is the surface upon which the force is exerted, and is usually measured in square inches. Thus pressure is commonly *measured* in *pounds per square inch* (psi). Using the metric system of measurement, pressure would be expressed as grams or kilograms per square centimeter. This is simply another expression of the force per unit of surface area upon which it is acting. Pressure will also support a column of liquid, as in a U-tube or manometer. In certain situations, it is more convenient to express pressure in terms of the height of the column of liquid which it will support. For example, inches, centimeters, or millimeters of mercury, or inches or centimeters of water, can be used as units of pressure. In diving computations, pressure is often expressed directly in feet of sea water. Pressure can also be expressed in atmospheres.

Kinetic Theory of Gases

(2) In order to understand the behavior of gases under variations of pressure and temperature, their molecular structure must be considered. Every gas is a collection of extremely small particles called molecules. The word "kinetic" indicates that these molecules are in constant *motion*, bumping into one another or bounding off the walls of their container. If temperature is reduced, this motion becomes slower, and fewer collisions occur. Finally, when a certain degree of cold is reached, the molecules become so sluggish that they tend to adhere to one another. At this point the gas turns into a liquid. Still further down the scale, the molecules freeze together and the liquid becomes a solid. If absolute zero (minus 459.7° F or minus 273.18° C) could be reached, all molecular motion would cease entirely.

(3) The molecules in a gas behave much like a swarm of bumblebees flying around in a box and bumping against its walls at random. Each time one bumps into the side, it exerts a momentary push; and if such collisions are frequent enough they add up to a continuous force. If the box is heated, the bees will fly faster and strike its walls more often. If it is chilled, they will become sluggish and have fewer collisions. The force on the walls will increase or decrease as a result of the change in temperature.

(4) With the molecules of a gas (fig. 1–11), the tiny impact of each collision is multiplied by billions per second on each square inch of surface, yielding a steady and measurable pressure. If the temperature is increased, the speed of each molecule increases correspondingly and the impacts become both more frequent and more forceful. The net pressure rises accordingly. If the same number of gas molecules are squeezed into half the original space, twice as many collisions will occur in a given length of time, and the observed pressure will be doubled. Therefore, pressure must increase both with increasing temperature and with decreasing volume. If more gas is forced into the same original space, this will also increase the number of collisions and raise the pressure.

Types of Pressure

(5) *Atmospheric pressure* is the result of the weight of the atmosphere producing a force on the surface of the earth. This pressure acts in all directions; and almost all structures, including our own bodies, either transmit the pressure freely or are exposed to the same pressure both inside and outside. The effects of pressure are thus usually neutralized or canceled, so we often ignore the fact that atmospheric pressure exists. However, if we could take a container and remove all the air from it, we would find that a

pressure of approximately 14.7 psi was acting on its walls. In other words, the miles of air above a square inch of surface area at sea level weigh about 14.7 pounds. The term "1 atmosphere" is used to denote a pressure of 14.7 psi. For example, a pressure of 147 psi can be expressed as 10 atmospheres. Indicating pressure in atmospheres is convenient in several situations in diving. For conversion to metric units, see table 1–2.

(6) *Gage pressure* indicates the *difference* between the pressure being measured and the surrounding atmospheric pressure. When we say that the pressure in a gas cylinder is 1,000 psi, we mean that the pressure is 1,000 psi *above* atmospheric pressure. Since ordinary gages can measure only such differences, their zero indicates atmospheric pressure. Except where otherwise specified, almost all pressure readings are gage pressure. When it is desirable to indicate positively that a pressure is gage, it is customary to express it as *pounds per square inch, gage* (psig).

(7) *Absolute pressure* (fig. 1–12) is the true or total pressure being exerted, and is the gage pressure plus 1 atmosphere of pressure. To obtain the absolute pressure, it is necessary to add 14.7 to the indicated gage reading if this is in psi. Absolute pressure is commonly expressed as *pounds per square inch, absolute* (psia). Absolute pressure can be expressed in any system of units if the amount equivalent to normal sea-level atmospheric pressure is added to the gage reading. If pressure is being expressed in atmospheres, 1 atmosphere is added to the number. The absolute pressure must always be used in equations describing the behavior of gases.

(8) The exact pressure of the atmosphere at any given place or time is measured by means of a barometer and is called *barometric pressure*. Because it is produced by the total weight of the atmosphere above the place of measurement, barometric pressure will be changed by anything which changes this weight. For ex-

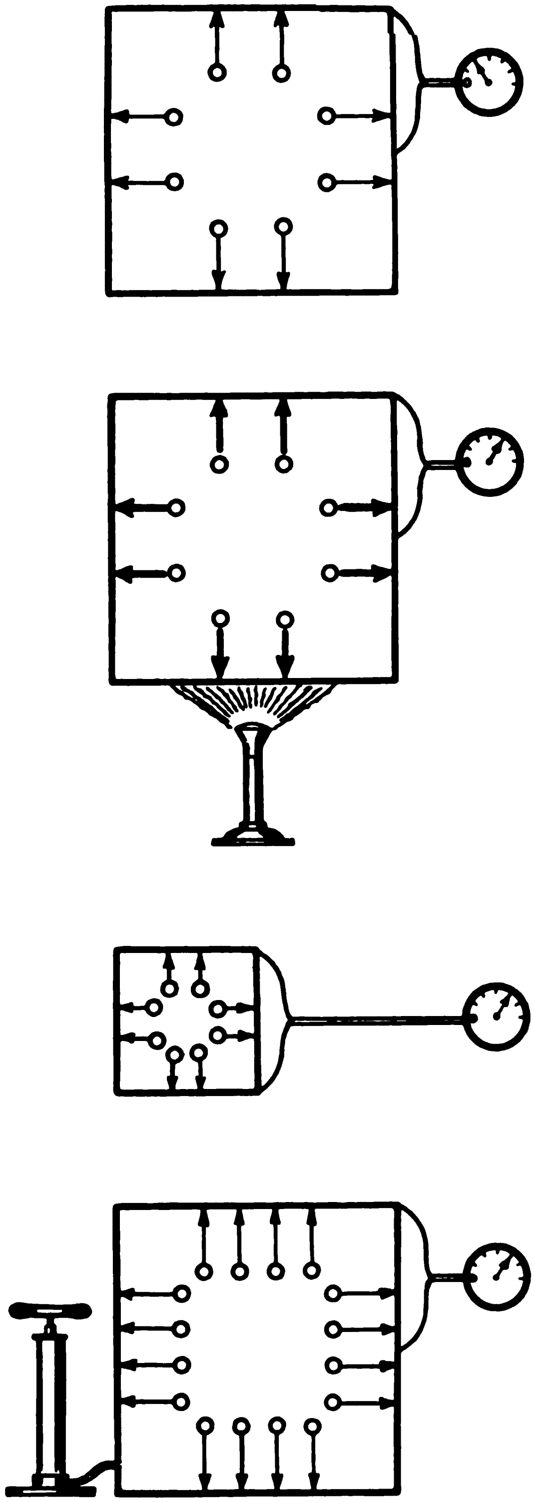


FIGURE 1–11.—Behavior of gas molecules (top to bottom). (a) Pressure is caused by the billions of impacts per second of gas molecules moving in container. (b) Heating the gas increases speed of molecular motion. Increased number and force of impact causes pressure to rise. (c) Decreasing volume of container increases number of impacts per unit of surface area, thus increasing pressure. (d) Forcing more gas into original container also increases number of molecular collisions and raises pressure.

TABLE 1–2.—*Table of conversion factors*

[U.S. units to metric units]

Length

1 inch	= 25.4 mm
	= 2.54 cm
1 foot	= 30.48 cm
	= 0.3048 m
1 statute mile	= 1.609 km
1 nautical mile	= 1.853 km

Area

1 sq in	= 6.45 cm²
1 sq ft	= 929.03 cm²
	= 0.0929 m²

Volume and capacity

1 cubic inch	= 16.39 cc
1 cubic foot	= 28,317 cc
	= 28.317 liters
	= 0.028317 cu m
1 quart	= 0.946 liter

Weight

1 ounce	= 28.35 gm
1 pound	= 453.6 gm
	= 0.454 kg
1 short ton	= 907.2 kg

Pressure

1 psi	= 70.3 gm/cm²
	= 0.0703 kg/cm²
	= 0.703 m of fresh water
	= 5.17 cm Hg
1 in. of fresh water	= 25.4 mm water
	= 2.54 gm/cm²
1 in. of mercury	= 25.4 mm Hg
	= 34.54 gm/cm²

ample, if one ascends in an airplane or by climbing a mountain, there is less atmosphere (and thus less weight of atmosphere) above. The barometric pressure is therefore lower, and barometric pressure can thus be used to measure altitude. Changes in barometric pressure are also caused by such factors as air temperature, the amount of water vapor in the atmosphere, and the movement of masses of air. Although these changes are usually small, they are of great importance in weather prediction. For measurement of barometric pressure and conversion factors, see 1.2.10(9)–(11).

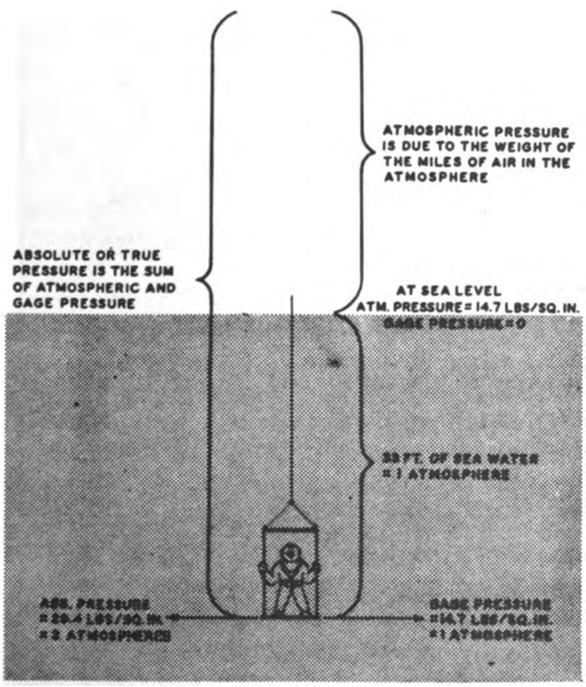
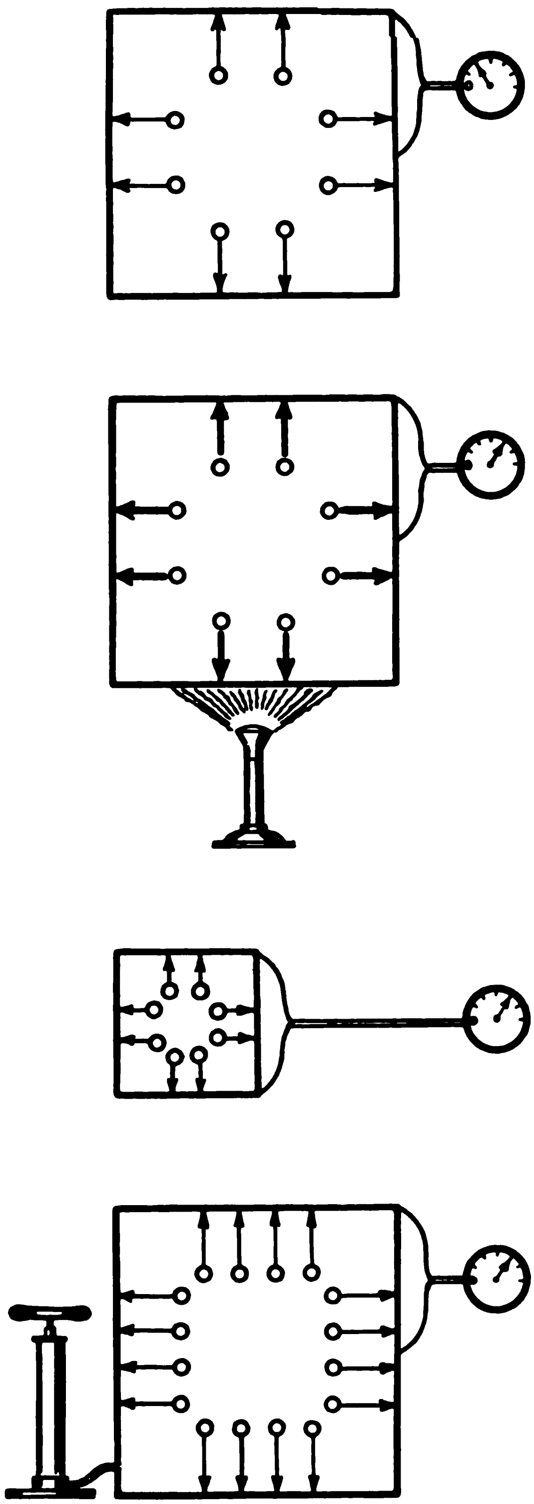


FIGURE 1–12.—Absolute pressure.

Liquid Pressure

(9) The *pressure* with which a diver is most directly concerned is that which is exerted by the surrounding *water* at his diving depth. In order to understand how this pressure is produced and how it acts, it is necessary to have certain basic information about the behavior of liquids in general. Water will be used for all examples in this discussion because of its concern to divers, but the information applies to other liquids as well.

(10) The pressure produced by a liquid is the direct result of its weight. A heavy liquid will naturally produce more pressure than a



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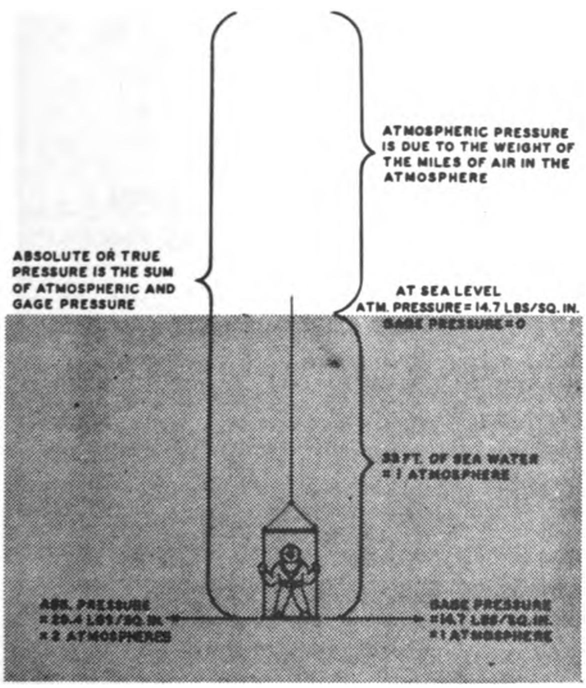

Figure 1–12.—Absolute pressure.

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(10) The pressure produced by a liquid is the direct result of its weight. A heavy liquid will naturally produce more pressure than a

lighter one. When we speak of weight in this sense and want to compare one substance with another, we use *density* as the yardstick. The density of a liquid (or of any other substance) is simply the *weight* of a specified *volume* of the substance (weight per unit volume). For example, we can say that the density of pure (fresh) water is 62.4 pounds per cubic foot. The density of average sea water is 64 pounds per cubic foot because of the added weight of the salts which are dissolved in it.

(11) Water is practically incompressible, so its density remains virtually the same regardless of the depth or pressure applied to it. As a result, the pressure exerted by water is directly proportional to its depth: the pressure exerted by 20 feet of water will be twice that exerted by 10 feet, and so on. If a tank 33 feet deep is filled with sea water, the pressure on one square foot of surface area on the bottom will be equal to the weight of the column of water above it. This column may be thought of as a stack of 33 1-foot cubes of water each weighing 64 pounds. The total weight would thus be 33×64, or 2,112 pounds, acting on 1 square foot of surface area. Since there are 144 square inches in a square foot, the pressure on each square inch in this case would be 2,112/144, or approximately 14.7 psi—1 atmosphere of pressure. This is the pressure exerted by the water above. The air above the water is exerting an additional 14.7 psi of pressure, so the absolute (total) pressure at a depth of 33 feet is 29.4 psia, or 2 atmospheres. Each additional 33 feet of descent will add an atmosphere (14.7 psi) of pressure. The absolute pressure exerted on a submerged body is the pressure of the water plus atmospheric pressure. Each foot of descent increases the pressure by 1/33 of 14.7 psi, or 0.445 psi. This figure is a very useful one to remember. Multiplying the depth in feet by 0.445 gives the water pressure at that depth in psi. Adding 14.7 psi to this gives the absolute pressure at the depth.

(12) Water pressure, like atmospheric pressure, is transmitted equally in all directions (fig. 1–13). The water pressure exerted on the sides and bottom of a tank is distributed evenly over all the area of the tank regardless of its shape. The pressure at any level in the tank is directly proportional to the depth at that level.

(13) The water pressure on a man who is standing under water is naturally greater at his feet than at his head. The body as a whole is largely composed of water and can be compared with a man-shaped bag of water. If such a contrivance were submerged, it too would have greater pressure at the feet than at the head; but one would not expect this to damage it or even change its shape. The water inside the man-shaped bag would freely transmit the external pressure, and at every point the pressure outside would be exactly balanced by an equal pressure inside. If no *difference* of pressure exists across any part of a structure, there will be no mechanical effect. The human body is more complicated

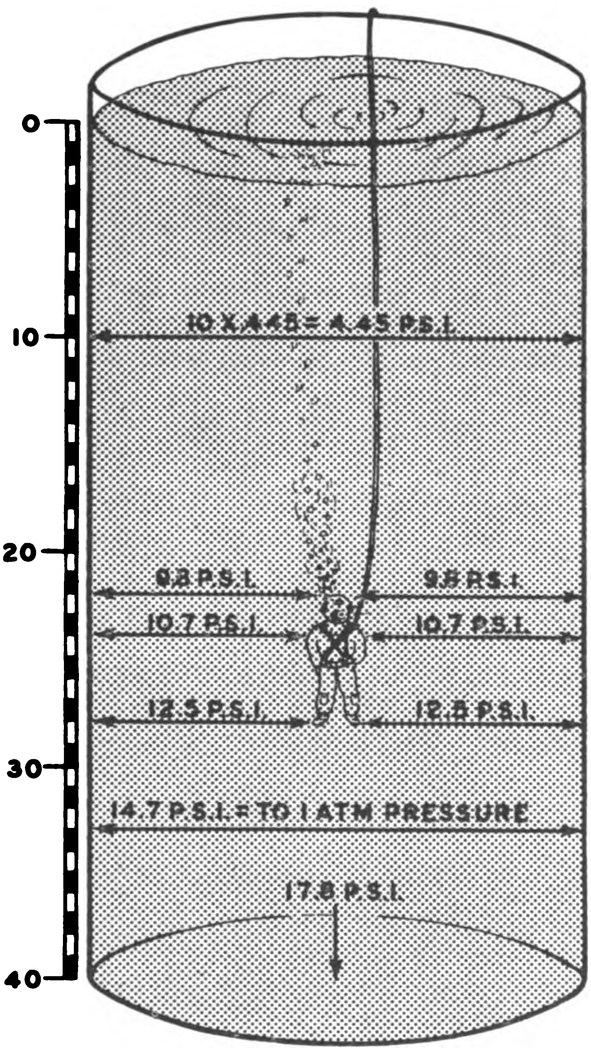

FIGURE 1–13.—Water pressure.

than this comparison indicates because it contains air spaces (lungs, sinuses, middle ear); but if the pressure exerted on these spaces is balanced by air at equal pressure inside, the net result is practically the same. The air which accomplishes this equalization is supplied at the proper pressure by the helmet diver's air hose or by the scuba diver's breathing apparatus. A more complete discussion of this subject, and of the effects of a failure to equalize pressure in these spaces, is presented in articles on "Squeeze."

Gas Laws

(14) The behavior of gases is affected by pressure, volume, and temperature; and these effects are closely interrelated. Several rules (called *gas laws*) which describe the behavior of gases under varying conditions have been formulated and named for their originators. These will be defined and explained. In considering and applying the laws, several things must be kept in mind:

(*a*) Any *unit* of pressure, volume, or temperature can be used, but the *same* unit must be used throughout the calculations. For example, it is all right to use cubic feet or liters or any other unit as the measure of volume, but it is not possible to start out with one unit and end up with another unless a *conversion factor* is used (tables 1–2 through 1–5). Either the Fahrenheit or centigrade scale can be used for temperature measurements, but one must not switch from one to the other. The same applies to units of pressure.

(*b*) Where pressure is involved, absolute pressure must be used (1.2.4(7)) in dealing with the gas laws.

(*c*) Where temperature is considered, you must use *absolute* temperature (1.2.4(2) and 1.2.10(8)). To convert to absolute temperature, add 460° to Fahrenheit readings or 273° to centigrade readings.

NOTE

The *density* of a gas, like the density of a liquid, refers to the weight per unit of volume. In the case of a gas, density depends not only upon the weight of the gas molecules but also upon the number of molecules present in the volume concerned. This number, in turn, depends on both pressure and temperature.

TABLE 1–3.—*Table of conversion factors*

[Metric units to U.S. units]

Length		*Area*	
1 cm	=0.394 in.	1 cm²	=0.155 sq in.
1 meter	=39.37 in.	1 m²	=10.76 sq ft
	=3.28 ft	1 sq km	=0.386 sq mi
1 kilometer	=0.621 mi		

Volume and capacity		*Weight*	
1 cc or ml	=0.061 cu in.	1 gram	=0.035 oz
1 cu m	=35.31 cu ft	1 kg	=35.27 oz
1 liter	=61.02 cu in.		=2.205 lb
	=0.035 cu ft		
	=33.81 fl oz		
	=1.057 quarts		

Pressure	
1 gm/cm²	=0.394 inch of fresh water
1 kg/cm²	=14.22 psi
	=32.8 feet of fresh water
	=28.96 inches of mercury
1 cm Hg	=0.193 psi
	=0.446 foot of fresh water
	=0.394 inch of mercury
1 cm of fresh water	=0.394 inch of fresh water

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TABLE 1-4.—*Table of conversion factors*

[U.S. units to other U.S. units]

Length

1 inch (in.)	=0.083 ft
1 foot (ft)	=12 in.
1 yard (yd)	=36 in.
	=3 ft
1 fathom	=6 ft
1 statute mile	=5,280 ft
1 nautical mile	=6,080 ft
	=2,026.7 yd

Area

1 sq in.	=0.0069 sq ft
1 sq ft	=144 sq in.
1 sq yd	=1,296 sq in.
	=9 sq ft
1 acre	=43,560 sq ft
	=0.00156 sq mi.
1 sq mile	=640 acres

Volume (cubic measurements)

1 cu in.	=0.00058 cu ft
1 cu ft	=1,728 cu in.
	=29.92 quarts
	=7.48 gallons
1 cu yd	=27 cu ft

Capacity (liquid measure)

1 pint (pt)	=16 fluid ounces
	=28.88 cu in.
1 quart (qt)	=2 pt
	=57.75 cu in.
1 gallon (gal)	=4 qt
	=231 cu in.

Weight (avoirdupois)

1 ounce (oz)	=0.0625 lb
1 pound (lb)	=16 oz
1 short ton	=2,000 lb

Weights of water

1 quart	=2 lb (fresh water)
1 cu ft	=62.4 lb (fresh water)
	=64 lb (sea water)

Pressure

1 pound per square inch (psi)	=2.31 ft of fresh water
	=2.25 ft of sea water
	=0.068 atm
	=2.036 in. Hg
1 atmosphere (atm)	=14.696 psi
	=29.92 in. Hg
	=33.9 ft of fresh water
	=33 ft of sea water
1 foot of sea water	=0.445 psi
1 inch of mercury (in. Hg)	=0.491 psi
	=1.133 ft of fresh water
	=13.60 inches of fresh water

TABLE 1–5.—*Table of conversion factors*

[Metric units to other metric units]

Length

1 millimeter (mm)	=0.1 cm
	=0.001 m
1 centimeter (cm)	=10 mm
	=0.01 m
1 decimeter* (dm)	=100 mm
	=10 cm
	=0.1 m
1 meter (m)	=1,000 mm
	=100 cm
	=10 dm
	=0.001 km
1 kilometer (km)	=1,000 m

Area

1 sq cm (cm^2)	=100 mm^2
1 sq m (m^2)	=10,000 cm^2
1 sq km (km^2)	=1,000,000 m^2

NOTE.—European usage employs a comma where we use a decimal point and a period where we use a comma (in large numbers).

Volume and capacity

1 cubic centimeter (cc) (or 1 millimeter (ml))	=0.001 liter
1 liter (l)	=1000.027 cc†
	=1,000 ml
	=0.001 cu m (m^3)
1 cubic meter (m^3)	=1,000 liter

Weight

1 milligram (mgm)	=0.001 gm
1 gram (gm)	=1,000 mgm
	=0.001 kg
1 kilogram (kg)	=1,000 gm

Weights of fresh water

1 cc or 1 ml	=1 gm
1 liter	=1 kilogram

Pressure

1 gram per square centimeter (gm/cm^2)	=0.001 kg/cm^2
	=1 cm of fresh water
1 kilogram per square centimeter (kg/cm^2)	=1,000 gm/cm^2
	=10 meters of fresh water
	=9.75 meters of sea water
	=73.56 cm Hg
	=0.968 atm
1 centimeter of mercury (cm Hg)	=13.6 gm/cm^2
	=13.6 cm of fresh water
1 centimeter of fresh water	=1 gm/cm^2
1 atmosphere	=1.033 kg/cm^2
	=760 mm Hg

*Seldom used.

†For almost all purposes, a liter is considered equal to exactly 1,000 cc.

(15) *Boyle's law* states that *if the temperature is kept constant, the volume of a gas will vary inversely as the ABSOLUTE pressure while the density will vary directly as the pressure.* In other words, if the pressure on a gas is doubled, the density also is doubled but the volume is decreased to one-half of the original volume.

(16) Boyle's law is important to divers mainly for an understanding of two important things: the compression of gas by the pressure of depth, and the relationship between pressure and volume in air supplies. Figure 1–14 illustrates the effect of depth pressure, using an open-ended cylinder (or bell) lowered to various depths as an example. If we assume that the bell is filled with air at normal pressure at the surface and that no air is furnished to it on its descent, the volume and density of the air inside will follow Boyle's law as the pressure exerted by the water increases. At the surface, the absolute pressure is 14.7 psi, or 1 atmosphere. When the bell is lowered to 33 feet below the surface, the water exerts an *additional* pressure of 14.7 psi, making the total (absolute) pressure 29.4 psi, or 2 atmospheres. As a result, the volume of the air is reduced to one-half of what it was at the surface, and its density is doubled. At 66 feet, the water exerts an excess pressure of 29.4 psi, and the total pressure therefore is 44.1 psi, or 3 atmospheres. The density is accordingly three times what it was at the surface, and the volume is reduced to one-third of the original. At 297 feet, the absolute pressure is 10 atmospheres; consequently the volume is one-tenth of what it was at the surface, and the density is 10 times as great.

(17) It is important for the diver to notice that the *relative* changes in pressure and the consequent changes in volume are greatest near the surface.

(*a*) This relative change can clearly be seen by noting what happens in terms of units of volume. Let us say that the original volume of air in the bell was 12 cubic feet. Descending to 33 feet compressed the air into a volume of only one-half of 12, or 6 cubic feet. Further descent to 66 feet reduced it to one-third or 4 cubic feet, while a descent to 99 feet reduced it to 3 cubic feet. The actual change in volume with each atmosphere of descent thus becomes smaller and smaller the deeper the bell goes.

(*b*) Consider another example: if the bell was refilled with 12 cubic feet of air at 264 feet (9 atmospheres absolute) and was then taken down 33 feet to 297 feet (10 atmospheres absolute), the volume would be reduced to 10.8 cubic feet—a volume change of one-tenth, or only 1.2 cubic feet compared to the 6-cubic-foot change in going from the surface to 33 feet.

(*c*) Note also that the same facts apply to ascent. If the bell contained 1 cubic foot of air at 10 atmospheres, this would expand only to a little over 1.1 cubic feet on ascending 33 feet to a pressure of 9 atmospheres. On reaching 2 atmospheres (33 feet), the air would expand to 5 cubic feet; and on being brought to the surface, the volume would double to 10 cubic feet. Ascending from 33 feet to the surface thus produced a greater change in actual volume than did ascending all the way from 297 feet to 33.

(18) Figure 1–14 also illustrates the change in the *diameter* of a gas-filled sphere or bubble which occurs with increasing depth. The *volume* of gas in this bubble will change in the same way as the volume of gas in the bell, but the corresponding change in diameter is always smaller than the change in volume. As depth increases and the volume change becomes less and less, the change in diameter becomes very small indeed. This explains why a gas-filled balloon does not appear to shrink to half its original size in descending from the surface to 33 feet, and why an ascending bubble does not seem to double its size in rising from that depth to the surface. The distinction between bubble volume and bubble diameter also arises in connection with the treatment of decompression sickness (1.3.9(17)).

(19) *Charles' law* states that *if the pressure is kept constant, the volume of a gas will vary directly as the ABSOLUTE temperature.* This means that volume increases when temperature is increased, and that if the absolute temperature is doubled the volume will double. If temperature decreases, so does volume. It follows that if volume rather than pressure is kept constant, as by heating air in a rigid container,

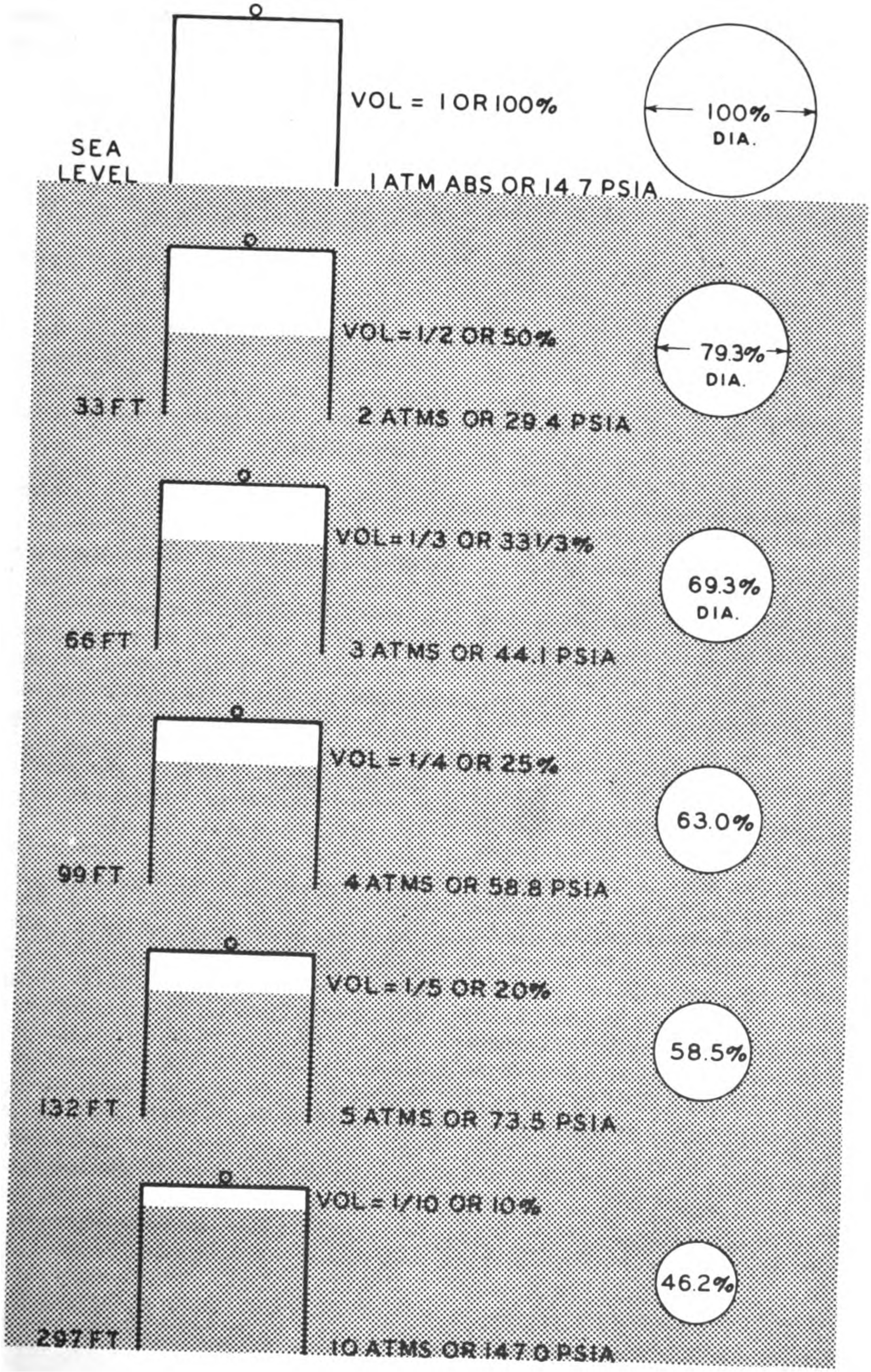

FIGURE 1-14.—Depth, pressure, and volume.

then the absolute pressure will increase in proportion to the absolute temperature. (Charles' law is sometimes called the law of Gay-Lussac.)

The General Gas Law

(20) Boyle's and Charles' laws can be combined to relate pressure, volume, and temperature in a general gas law. This is expressed in the following basic equation:

$$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2}$$

where

P_1=initial pressure (absolute)
V_1=initial volume
T_1=initial temperature (absolute)

and

P_2=final pressure (absolute)
V_2=final volume
T_2=final temperature (absolute)

Note that where either P, V, or T will be the same or nearly so on both sides of the equation, that factor can be canceled (removed from both sides of the equation). Temperature in example (*a*) below and volume in example (*b*) can be omitted in this way, thus simplifying the calculation. They need not even be known. In example (*c*), all three factors change, and the equation must be used as it stands. Except in the case of a value which does not change, there can be *only one unknown quantity* in the equation. Simple algebra should be reviewed and the examples examined for an understanding of how the equation is rearranged to solve for the unknown in each case.

(*a*) An air compressor is known to have a maximum intake capacity of 12 cubic feet of free air per minute. How many cubic feet can it deliver to ventilate the helmet of a diver at 165 feet (73.5 psig)? Assume that the air and water temperatures are approximately equal and that the pressure is ample to overcome resistance at the depth.

$P_1=0+14.7=14.7$ psia
$V_1=12$ cu ft
$T_1=T_2$ (cancel)
$P_2=73.5+14.7=88.2$ psia
$V_2=?$

Cancel T_1 and T_2 in the equation:

$$P_1V_1=P_2V_2$$

Rearrange the equation to solve for V_2:

$$V_2=\frac{P_1V_1}{P_2}$$

Substitute values and solve:

$$V_2=\frac{14.7\times12}{88.2}=2 \text{ cu ft}$$

Observe that in some problems, like this one, it will simplify the calculations if the absolute pressure is expressed in atmospheres rather than in psia. The absolute pressure at 165 feet is 6 atmospheres, so

$P_1=1$ atm
$V_1=12$ cu ft
$P_2=6$ atm

and

$$V_2=\frac{1\times12}{6}=\frac{1}{6}\times12=2 \text{ cu ft}$$

(*b*) A self-contained apparatus cylinder is charged rapidly to a pressure of 1,785 psig and reaches a temperature of 140° F in the process. What will the gage pressure be when a diver uses the cylinder in 40° F water?

$P_1=1785+15=1{,}800$ psia
$V_1=V_2$ (cancel)
$T_1=140+460=600°$ F (absolute)
$P_2=?$
$T_2=40+460=500°$ F (absolute)

Cancel V_1 and V_2, and rearrange the equation to solve for P_2:

$$P_2=\frac{T_2P_1}{T_1}$$

Substitute values and solve:

$$P_2=\frac{500\times1800}{600}=1{,}500 \text{ psia}$$

$$1500-15=1{,}485 \text{ psig}$$

(*c*) An air supply tank is known to deliver 10.8 cubic feet of free air at the surface, measured at 80° F, for every 100-psi drop in tank pressure. What would the corresponding volume be at 132 feet in 40° F water?

$P_1=1$ atm (absolute)
$V_1=10.8$ cu ft
$T_1=80°+460°=540°$ F (absolute)
$P_2=5$ atm (absolute)
$V_2=?$
$T_2=40°+460°=500°$ F (absolute)

Rearrange the equation to solve for V_2:

$$V_2=\frac{P_1V_1T_2}{T_1P_2}$$

Substitute values and solve:

$$V_2=\frac{1\times10.8\times500}{540\times5}=2 \text{ cu ft}$$

Squeeze

(21) Normally, pressure itself and the compression of gases under pressure have very little effect on the diver's body. However, when for some reason transmission and equalization of pressure fail to occur, destructive differences in pressure can develop. Accidents which result from such failures (usually during descent) can be classified under the term *squeeze*. The most serious accident of this sort occurs when a diver in helmet and dress falls an appreciable distance under water. The sudden increase in external pressure will compress the air in the rig in accordance with Boyle's law. If the amount of air present is sufficient to keep the rigid helmet full of air at the increased pressure, the internal and external pressures will remain in balance, and there will be no serious consequences. But if all the available air has been compressed into the helmet and the inside pressure still is not as high as the outside pressure, the excess of external pressure will act through the dress upon the diver's body and tend to crush him into the helmet. If the unbalanced difference in pressure is large, this crushing may actually take place. The fact that a certain amount of descent near the surface causes greater compression of gas than the same amount of descent at deeper depth has been discussed in paragraph (17) above. This explains why a diver who falls a given distance during a relatively shallow dive is in greater hazard than one who falls an equal number of feet during a deep dive.

(22) The same effect of squeeze can result if for any reason the pressure in a diver's air hose drops much below depth pressure and if his nonreturn valve fails to retain pressure in the helmet. In this case, the helmet is simply vented to lower pressure, and the air is forced out of the rig by the surrounding pressure. With nothing to counterbalance it, the entire pressure of the depth will then be acting on the diver's body, tending to force it into the helmet. Even a few psi can add up to a tremendous force when the effective surface area is considered, so this accident could be fatal even in relatively shallow water. Similar accidents can occur with a hose-supplied facemask.

(23) Squeeze can occur on a smaller scale during any descent in which one of the body's air spaces, or any rigid air space attached to the surface of the body, fails to equalize pressure. For example, if a skindiver wears ordinary goggles and tries to deep dive with them, he may experience eye squeeze. When he leaves the surface the goggles contain air at normal pressure, and no air can be added during descent. As the pressure increases outside, a difference in pressure develops between the inside and the outside of the goggles. If the goggles are made of soft rubber, they may yield enough to let the pressures equalize by compression of air; but if they are rigid, the difference will simply increase as the diver descends, and something will eventually have to yield. The external pressure is being transmitted freely throughout the diver's body, so his eyes and their surrounding tissues are under a much higher pressure than the air with which they are in contact. The difference in pressure is acting across them, much as if a suction cup were being applied. This action may cause bleeding into the skin and membranes, and more serious damage may possibly result. The same harmful sequence of events can occur because of unequalized differences in pressure wherever these develop in or on the body. Injuries from these physical effects of squeeze are discussed in further detail in other sections.

1.2.5 GAS MIXTURES

(1) The diver deals with mixtures of gases, and it is important for him to understand how

gases behave in mixtures. Air is the most common of these mixtures. To simplify the discussion, its composition will be considered to be 80 percent nitrogen and 20 percent oxygen. Mixtures of helium and oxygen; nitrogen and oxygen (in different percentages than in air); or oxygen, helium, and nitrogen are also utilized by the diver.

(2) In any mixture of gases, each of the several gases contained in the mixture exerts its share of the total pressure being produced. *Dalton's law* states that *the total pressure exerted by a mixture of gases is the sum of the pressures that would be exerted by each of the gases if it alone were present and occupied the total volume.*

(3) The *partial pressure of a gas* is proportional to the number of molecules of the gas present in a specified volume at a given temperature. If a container were filled with pure (100 percent) oxygen at normal atmospheric pressure, then the partial pressure of oxygen in that container would be 14.7 psi, or 1 atmosphere. The partial pressure of oxygen in this case would equal the total pressure because no other gas molecules were present. If an equal number of nitrogen molecules were then introduced into the container without letting any oxygen escape and without changing the temperature, the total (absolute) pressure would become 2 atmospheres. We would now have a gas mixture consisting of 50 percent oxygen and 50 percent nitrogen. The number of oxygen molecules in the container would be the same, so the partial pressure of oxygen would remain the same: 1 atmosphere. This pressure now would be only half of the total, because the partial pressure of nitrogen also would be 1 atmosphere. If the size of this container were reduced one-half without letting any gas molecules escape, and if the temperature were kept constant, the total pressure would be doubled again: it would now be 4 atmospheres. The number of all gas molecules per unit volume, and the number of molecules of each gas per unit volume, would also be doubled. Therefore, the partial pressures of both nitrogen and oxygen would become 2 atmospheres. Changes in temperature cause changes in partial pressures in proportion to the change in absolute pressure. For example, if a container of gas filled with nitrogen and oxygen were heated enough to double the absolute pressure, the partial pressures of the nitrogen and the oxygen would also be doubled (1.2.4(19)).

(4) As illustrated in figure 1–15, air at 14.7 psi is 20 percent oxygen and 80 percent nitrogen by volume. The oxygen exerts 20 percent of the total pressure, or 2.94 psi, and the nitrogen exerts 80 percent of the total pressure, or 11.76 psi. If the total absolute pressure exerted by the air is increased to 73.5 psi, or 5 atmospheres (which is equivalent to the absolute pressure maintained within a diver's suit at 132 feet of depth), the oxygen still exerts 20 percent of the total absolute pressure and the nitrogen 80 percent of the total absolute pressure. Therefore, the partial pressure exerted by the oxygen is now 14.7 psi, or 1 atmosphere of pressure; and the partial pressure exerted by the nitrogen is now 58.8 psi. If the total absolute pressure exerted by air is increased to 220.5 psi, or 15 atmospheres of pressure (which is equivalent to the absolute pressure maintained in a diver's suit at 462 feet under water), the partial pressure exerted by the oxygen is still 20 percent of the total pressure exerted. The partial pressure exerted by the oxygen, therefore, is 44.1 psi, or 3 atmospheres; and the partial pressure exerted by the nitrogen is 176.4 psi. The dangers presented by such partial pressures are discussed in section 1.3, which covers the indirect physiological effects of pressure, nitrogen narcosis, and breathing media. Observe that although the partial pressure of a gas in a mixture may be insignificant at atmospheric pressure, it can become very important as the pressure of the mixture rises (the partial pressure of water vapor in a gas mixture can generally be ignored in diving). For example, 2 percent carbon dioxide in a mixture breathed at a depth of 132 feet (5 atm abs) will have the same partial pressure and the same physiological effect (see 1.3.5(8)) that 10 percent carbon dioxide would have at the surface.

(5) *Gas diffusion* is the process of intermingling or mixing of gas molecules. If two gases are placed together in the same container, they will eventually mix together completely even though the molecules of one gas are heavier

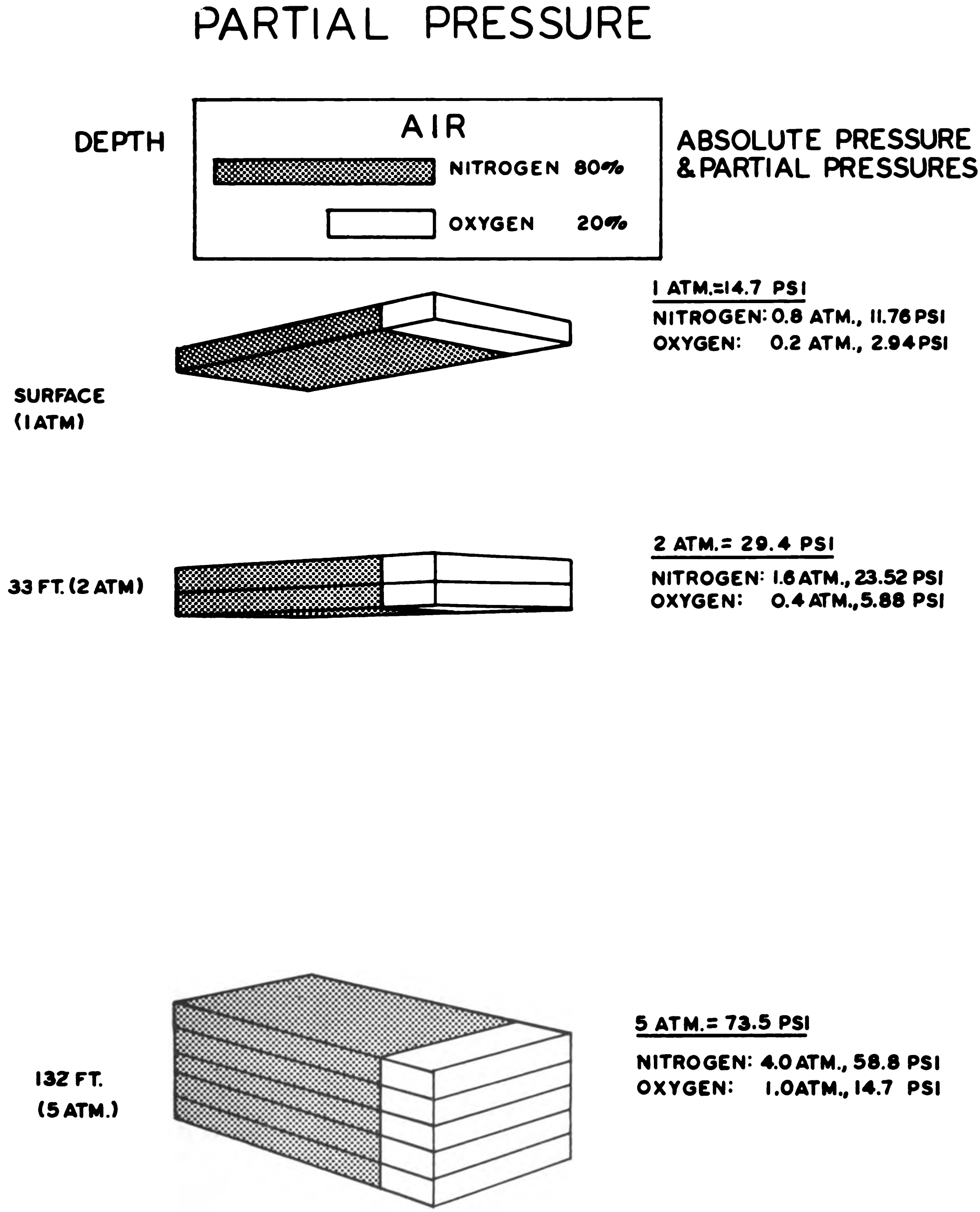

FIGURE 1-15.—Partial pressure. At 5 atmospheres absolute, partial pressure of oxygen in air is approximately equal to partial pressure of pure oxygen at surface.

than those of the other. This mixing takes place because of the constant motion of gas molecules. For the same reason, gas will also diffuse through the surface of a liquid, throughout the liquid itself, and through thin sheets (membranes) of many types of material.

(6) The amount of an individual gas which will move through a permeable membrane depends upon the partial pressure (or number of molecules) of the gas on both sides of the membrane. If the partial pressure is higher on one side, the gas will tend to move to the other side until the partial pressures are equalized. In their constant motion, molecules are actually passing through the membrane in both directions at all times; but more will move from the side where they are most numerous. When the partial pressures are equalized, the numbers passing in both directions will be equal (equilibrium), and there will be no further net shift of the gas.

1.2.6 DEHYDRATION OF AIR SUPPLY

(1) As previously stated, air contains water vapor in varying amounts, and one of the problems in diving operations arises when moisture has to be removed from the diver's air supply. Reconditioning the air is based on use of a table (table 1–1) and a "dewpoint temperature curve" (fig. 1–16). It is important to know how to use this table, and the following explanation is therefore included:

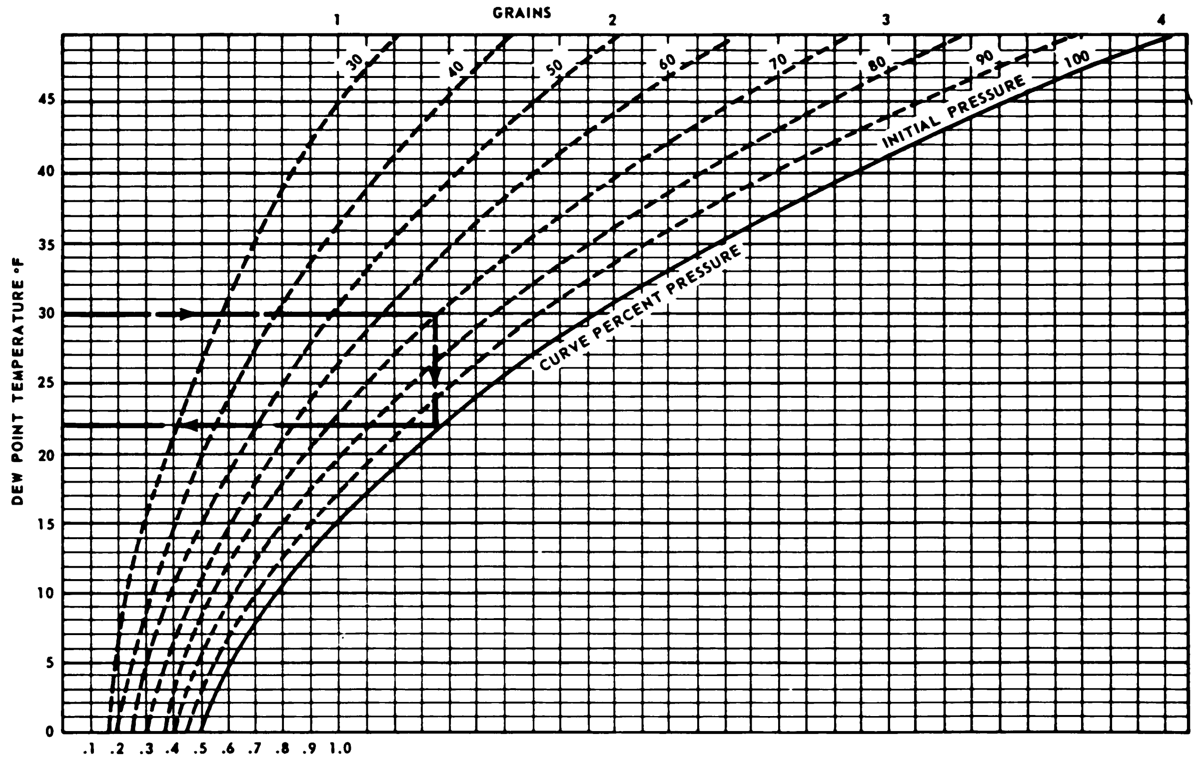

FIGURE 1–16.—Dewpoint temperature curve. Weight in grains of the aqueous vapor contained in a cubic foot of saturated air. (To find corresponding dewpoint (assuming original air 100 percent relative humidity for new pressure), start at temperature on left. Example: 30° temperature at 70 percent initial pressure=22° (dewpoint) with 1.36 grains of aqueous vapor.)

(*a*) *Dewpoint* is that temperature at which air must be cooled, at constant pressure, in order to become saturated and below which precipitation of moisture occurs. It varies with the moisture content of the atmosphere.

(*b*) *Absolute humidity* is the mass per unit volume of water vapor in the atmosphere at a given temperature. It can be expressed in grains per cubic foot.

(*c*) *Relative humidity* is the ratio between the water vapor present in the air and the water vapor that would be present if the air were saturated at the existing temperature. This is determined by the existing dewpoint and its relationship to the wet- and dry-bulb readings on a hygrometer. When air is saturated, the dewpoint, wet-bulb, and dry-bulb readings are all the same.

(2) An inspection of the *dewpoint temperature* chart (fig. 1–16) will show, by comparison of the entries in the column marked "Temp." with the figures set opposite the various temperatures, that a change in temperature causes a change in humidity; e.g., saturated air at 40° F contains 2.849 grains of water vapor per cubic foot, whereas at 30° F it contains 1.935 grains. Therefore, cooling will cause precipitation, and is the reason for rainfall.

(3) The amount of moisture that can be removed from the air depends upon the ability of the air-cooling system to reduce the dewpoint temperature of the air. In the case cited in (2), we see that reducing the dewpoint temperature of the saturated air from 40° to 30° F would cause the precipitation of 0.914 grain by weight ($2.849-1.935=0.914$) of moisture from each cubic foot of air. Since it would be precipitated at 30° F, it would be in the form of slush ice. The air at 30° F would contain 1.935 grains of moisture per cubic foot and would be saturated (100 percent relative humidity). Any further reduction in temperature would cause further precipitation. The slush ice formed could be discharged from the cooler through the bow valve, if done properly, before it solidified.

(4) Because the cooling agent consists of sea water circulating through the cooler, it is obvious that the degree of dehydration possible by cooling depends entirely on the temperature of the sea water. In the above case, 30° F would be called the dewpoint temperature since the air is saturated. However, as shown below, further reduction of the dewpoint may be brought about by expansion. A cubic foot of saturated air at 34° F (table 1–1) contains 2.279 grains of water vapor. For an example, the initial air pressure from the compressors can be assumed to be 150 psi (gage), or 164.7 psi (absolute); the reducing valve can be assumed to be set at 100 psi (gage), or 114.7 psi (absolute). The reduction in pressure from 150 psi to 100 psi would, in accordance with Boyle's law, reduce the density of the air to approximately 70 percent. Therefore the air, instead of having 2.279 grains of water vapor, would now contain only 70 percent of 2.279 grains, or 1.596 grains of water vapor. Thus the dewpoint would be lowered to 25.5° F by the reduction in pressure, and consequently the diver's air at temperatures above 25.5° F would not precipitate moisture and freezing could not occur. This example demonstrates that the air becomes relatively drier as it expands.

(5) To *use* the *curves* (fig. 1–16), run a line from the dewpoint temperature scale to the percent pressure scale. From this intersection drop a perpendicular line to the initial pressure curve, and then run a line from this point to the dewpoint scale. Using the dewpoint as indicated at this point on the scale, refer to table 1–1 for the grains of water vapor. Otherwise, the perpendicular line between the percent pressure and initial pressure curves can be extended to the base of the curve, and the figure for aqueous vapor determined by interpolation.

(6) It has never been found necessary in diving to reduce the aqueous vapor below 1.355 grains. Because air that is completely dehydrated would probably be injurious to the diver, the dewpoint should not be lowered beyond that necessary to prevent freezing of the diver's air line.

(7) In addition to the expansion of air caused by the main reducing valve, there is a further expansion at the diver's air-control valve. This expansion results from a drop in pressure of approximately 15 psi at the valve.

(8) When the air-cooling system is in operation, it is possible to maintain desired air temperatures by the use of bleeders. These are short lengths of hose, one to three in number, connected to outlets on the diving mains on the opposite side from which diving is being conducted. The bleeders are weighted a few feet below the surface of the water to eliminate noise. To raise the temperature in the diving air mains, it is only necessary to increase the flow of air in the mains by opening the bleeders as much as required; to lower the temperature in the diving air mains, the flow of air is decreased

and the bleeders are cut out. When using the air-cooling system, an appropriate record should be maintained.

1.2.7 GAS ABSORPTION IN LIQUIDS

(1) When a liquid is exposed to a gas, molecules of the gas will diffuse into the liquid. The process is much like that of gases diffusing through a membrane, but here the point of equilibrium is influenced by the solubility of the gas in the liquid—the number of molecules of gas the liquid will take up in solution at a given partial pressure. When equilibrium is reached, the liquid contains the dissolved gas at a *tension* equal to the partial pressure of that gas in the mixture to which the liquid is exposed.

(2) *Henry's law* states that *the amount of a gas that will dissolve in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas.* The term *amount*, as used here, refers to the number of molecules, or mass (weight) of the gas. However, at a given temperature and pressure, the volume of a gas is proportional to the mass, so we can speak of amounts of dissolved gas in terms of the volume they would occupy in free gaseous form under standard conditions of temperature and pressure at the surface. When a gas is *in solution*, its actual volume is negligible. The volume of a liquid thus shows no increase when a gas is dissolved in it. If a certain quantity of a liquid will absorb 1 quart of a gas at 1 atmosphere of partial pressure, it will absorb an additional quart when the partial pressure of the gas is increased to 2 atmospheres. The average man's body contains about 1 quart of dissolved nitrogen absorbed from the air he breathes at the surface. If he breathes air at 5 atmospheres total pressure for a long enough period for complete gaseous equilibrium to be reached (*up to 24 hours*), his body will then contain about 5 quarts of gas (in terms of volume measured at the surface). The *tension* of dissolved nitrogen throughout his body will be equal to the partial pressure of nitrogen in the air in his lungs: about 80 percent of 5 atmospheres, or 4 atmospheres, when equilibrium is reached. At this point, the man is said to be saturated with nitrogen at that pressure.

(3) If a diver whose body was *saturated* with nitrogen at a tension of 4 atmospheres were suddenly brought up to the surface, the tension of dissolved gas in his body would then be higher than the total pressure surrounding him. The nitrogen would be in a *supersaturated* solution, and some of the excess gas might leave the solution in the form of bubbles. This is believed to be the cause of *decompression sickness.* The same situation exists when a bottle of carbonated beverage is opened. In this case the gas is carbon dioxide, but the same principles apply. As long as the cap is on, the total pressure in the bottle matches the tension of the dissolved gas. When the cap is removed, the pressure on the liquid drops, and the excess pressure of dissolved gas causes bubbles to form. If the pressure in the bottle were released very slowly, the excess gas would gradually diffuse out of the liquid and no bubbles would form. In a similar manner, a diver can be brought up safely if his ascent is managed in such a way that enough nitrogen can escape by diffusion to avoid dangerous supersaturation. The process of gas absorption and elimination is very important in diving and is discussed further in section 1.3 on the *indirect effects of pressure.*

(4) The basic idea of *solubility* must be *distinguished from Henry's law*, which simply expresses the effect of partial pressure on the amounts of gas that will dissolve in a liquid. For example, the solubility of nitrogen in oil or fat is about five times its solubility in water at the same partial pressure. If a certain weight of water will take up about 1 liter of nitrogen at 1 atmosphere of pressure, the same weight of fat will take up about 5 liters of nitrogen at the same partial pressure. According to Henry's law, if the partial pressure were doubled, the water would then take up about 2 liters and the fat about 10. The pressure effect does not change the fact that nitrogen is approximately five times as soluble in fat as in water. Temperature also affects the solubility of gases: the lower the temperature, the higher the solubility. This is why a warm bottle of carbonated beverage forms bubbles much more actively than does a cold one, and why heating water causes bubbles to appear in it long before the boiling point is reached. In the latter case, air that was dissolved in the water must come out of solution because its solubility decreases as the temperature rises.

(5) The *difference* between the partial pressure (or tension) of a gas inside a container (or liquid) and its partial pressure outside the container is the force which causes the gas to diffuse through a membrane or a liquid. The size of the difference is one of the main factors controlling the *rate* of diffusion. The difference between internal and external partial pressure or tensions is sometimes called the *gradient* to distinguish it from other pressure differences not directly concerned with gas transfer. If a gas-free liquid is exposed to a gas, the inward gradient for the gas will be high at first, and the rate at which molecules of gas migrate into the liquid will be high. As the gas tension of the liquid rises, the gradient decreases, and the rate of transfer progressively slows. Because of the decreasing gradient, gas saturation or desaturation of a liquid proceeds rapidly at first but may take a long time to become complete.

1.2.8 BUOYANCY

Archimedes' Principle

(1) The buoyant effect of liquids is expressed by *Archimedes' principle*. This states that *any object wholly or partially immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced.* Figure 1–17 illustrates the following example: A diver, with his helmet and dress, weighs 384 pounds. If he inflates his dress so that he displaces 6.5 cubic feet of water, he will be buoyed up by a force equal to the weight of 6.5 cubic feet of water. Because sea water weighs 64 pounds per cubic foot (1.2.4 (10)), the buoyant force acting on this diver would be $6.5 \times 64 = 416$ pounds. This force is 32 $(416 - 384)$ pounds more than his total weight. Such an excess of buoyant force is called positive buoyancy. In this example, the diver would actually float with half a cubic foot of his vol-

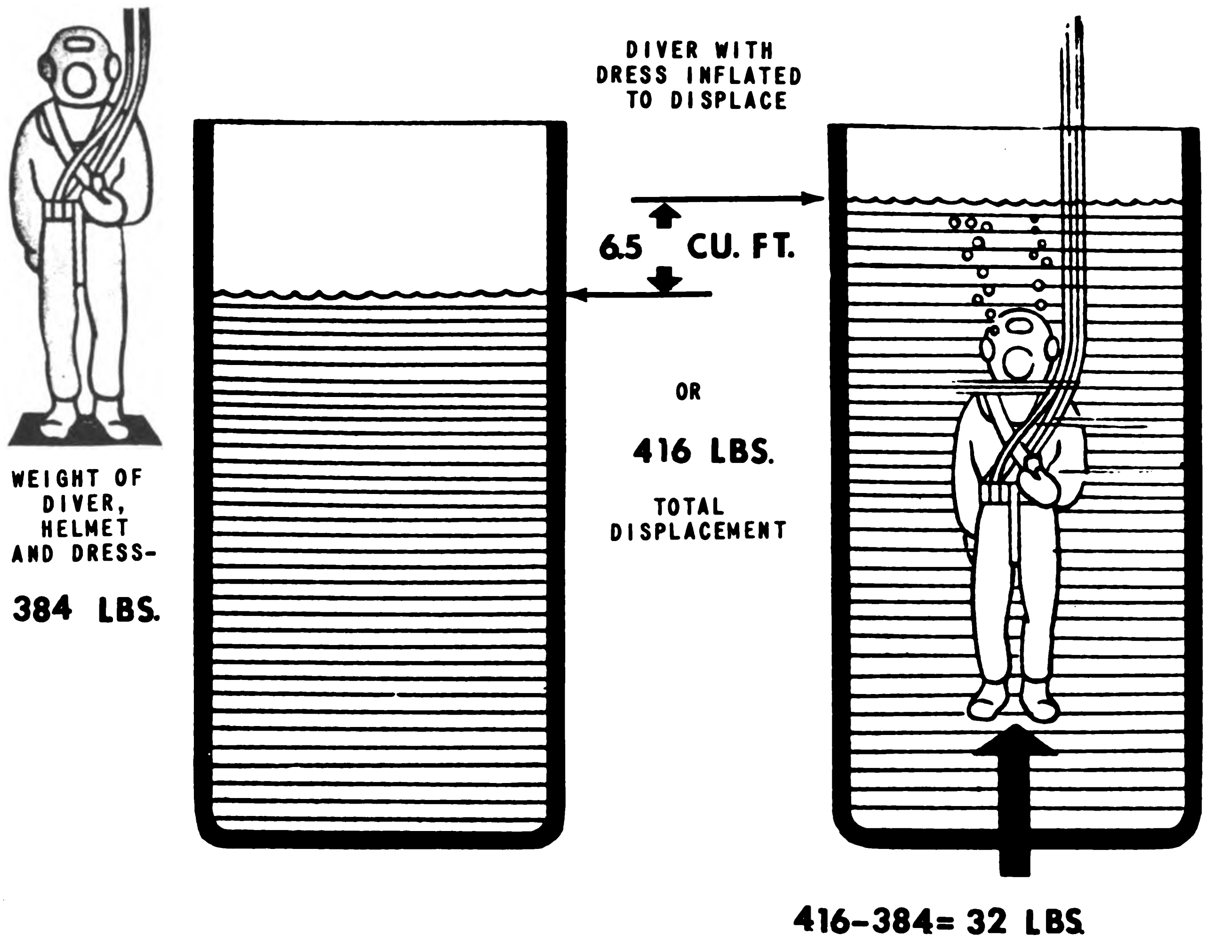

Figure 1–17.—Buoyancy (Archimedes' principle).

ume out of water. The volume of water displaced would then be 6 cubic feet, the weight of which ($6 \times 64 = 384$ pounds) would just equal his own weight. To give himself *neutral buoyancy*, with which he would neither rise nor sink in the water, the diver could either exhaust one-half of a cubic foot of air from his dress or wear an additional 32 pounds of weight. If he required *negative buoyancy* (the state of being heavy in the water), he would have to add still more weight or let out more air.

(2) If the same diver were submerged in fresh water rather than sea water, the buoyant force would be less because the density of fresh water is less than that of sea water. Fresh water weighs 62.4 pounds per cubic foot, compared with 64 for sea water, so the weight of the volume of water displaced would be 405.6 (6.5×62.4) pounds instead of 416.

(3) A diver in helmet and dress normally maintains negative buoyancy in order to remain underwater and have a good foothold on the bottom. If he allows his dress to become overinflated, he will gain positive buoyancy and begin to ascend. As he rises, the surrounding pressure decreases and the air in his suit expands. This increases his displacement and gives him even more positive buoyancy. Unless he can exhaust the excess air promptly, he will continue to rise at an increasing rate. Being carried to the surface in this manner is known as *blowing up* (1.6.10). The reverse of this process occurs when the diver falls or otherwise descends too rapidly. The compression of air in the dress decreases his displacement and makes him increasingly heavy. Other aspects of such an accident (squeeze) are discussed in sections 1.2 and 1.3.

(4) Even a surface swimmer is aware of buoyancy and knows that he is "lighter" in the ocean than in fresh water. Although most people can float quite well in sea water, a few cannot because their average body density is greater than that of the water, and their bodies thus weigh more than the water they displace. Two main factors determine whether a man's body will have positive or negative buoyancy. First, fat is lighter than muscle and bone and weighs less than water; therefore a fat person generally floats more easily than a lean one. The other important factor is lung capacity. The air space in a man's lungs buoys him up much like a pair of invisible water wings. Lung capacity varies with the individual, and almost everyone has observed that he is more buoyant with a full breath than when he exhales. When a man skin dives (holding his breath), the air in his lungs is compressed as he descends, so he becomes less and less buoyant the deeper he goes. If he starts with a full breath at the surface, the average man will become negatively buoyant after descending 15 to 20 feet. Some skin divers may find themselves as much as 10 pounds "heavy" at their maximum depth and may have to swim vigorously to start ascent.

(5) A self-contained diver wearing a rubber exposure suit is buoyant because of the air trapped between the suit and his body. He may have to use 5 to 30 pounds of diving weights to offset his buoyancy. When he descends, the trapped air is compressed, and he becomes heavier and heavier. In some such cases, the diver may have difficulty returning to the surface unless he drops some of his weights.

(6) Another important application of Archimedes' principle is in *salvage work* where buoyancy is used to raise heavy objects off the bottom. This raising can be done by sinking an airtight container of suitable size and strength (steel pontoon, collapsible rubber pontoon, etc.) and attaching it to the object. Buoyancy is then obtained by expelling the water or by inflation. The lifting capacity of any container equals the weight of the water it will displace, minus its own weight.

Laws of Flotation

(7) The laws based on Archimedes' principle can be summarized as follows:

(*a*) A body sinks in a fluid if the weight of fluid it displaces is less than the weight of the body.

(*b*) A submerged body remains in equilibrium, neither rising nor sinking, if the weight of the fluid it displaces is exactly equal to its own weight.

(*c*) If a submerged body weighs less than the volume of liquid it displaces, it will rise and float with part of its volume above the surface. A floating body displaces its own weight of a liquid. (The volume of liquid displaced by a floating body has the same weight as the body itself.)

1.2.9 ENERGY

(1) *Energy* is defined as the *capability of doing work.* It exists in several forms and can be changed from one form to another and stored in various ways. *Heat*, *electricity*, *light*, and *sound* are all forms of energy. Most of the energy used by man originally came from the sun in the form of light and heat, and was stored chemically by growing vegetation which became fuel or food. When a man lifts a weight, he is doing work with energy liberated from food by chemical reactions in his body. Even when he speaks, he is doing work and transforming a little of his energy into the energy of sound waves. The subject of energy is large and complex, and only those aspects that have special importance because of unusual effects underwater will be discussed here.

Light

(2) Even the process of seeing involves energy. An eye sees an object because the energy of light is reflected from the object in different colors and intensities. This light enters the eye and triggers nerve impulses to the brain. These impulses are given certain interpretations because humans are accustomed to the way light behaves in air. Because light behaves a little differently in water, a diver may find that his eyes deceive him. Straight lines sometimes appear bent, and objects appear larger and closer than they actually are. If the water is muddy, the diver may see poorly or not at all. Even if the water is relatively clear, natural shadows may be lacking and colors will be changed.

(3) When light rays pass from a medium of one density to a medium of a different density, they are usually bent from their normal course. This effect is known as *refraction*. In the case of light rays being reflected from an object in the water to a man's eye in the air, the light is refracted or bent in such a manner as to give him a false impression of the position and size of the object. This refraction is exactly what happens when a diver peers at an object from his air-filled helmet or face mask. The top of any object he looks at appears to be higher and the bottom appears to be lower (figs. 1–18 and 1–19). This refraction accounts for the deception of size and hence of distance. The distortion ratio caused by this effect is three-fourths; i.e., an object 20 feet away in the water appears to be only three-fourths of that distance, or 15 feet.

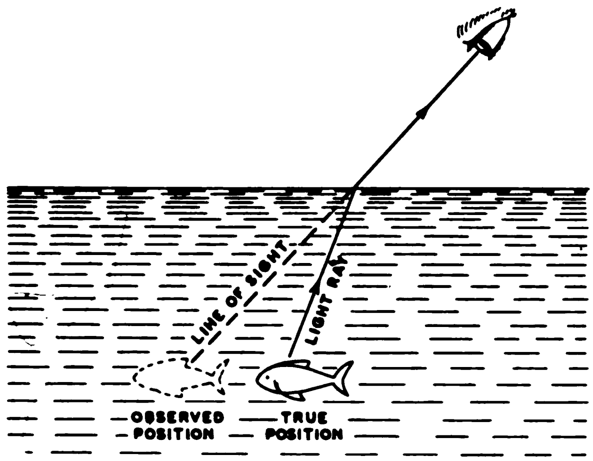

FIGURE 1–18.—Refraction.

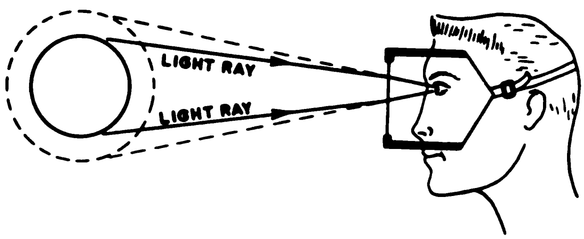

FIGURE 1–19.—Magnification.

(4) Generally, underwater visibility depends upon four main variables:

(*a*) The conditions of illumination.

(*b*) Diffusion, or scattering of light rays.

(*c*) Absorption of light rays in water.

(*d*) Turbidity.

(5) The brighter the day, the greater the amount of *light* (*illumination*) that enters the water. Normally, as a diver descends in water the total light gradually decreases. However, turbid water may be found in layers. Thus a relatively clear layer can at times be found under turbid water or at the ocean's bottom.

(6) *Absorption* of *light* in water is that process whereby light is apparently filtered by the water and reduced in intensity. White light consists of all the colors of a rainbow; i.e., each color is actually a component of white light. If

any of these colors were removed, the light would no longer be white. Such is the case when light penetrates deep enough in water. It first loses its red, then at somewhat greater depths the yellow is filtered out. At this point, most objects take on a blue color, and red objects appear black.

(7) *Diffusion* is the result of *light* rays being deflected and scattered by water molecules and foreign particles suspended in the water. This scattering somewhat reduces the total illumination. Diffusion is beneficial, however, because it is responsible for throwing light rays into crevices, caves, and other dark areas. If it were not for this effect, any object not in direct line with the sun's rays would have practically no illumination.

Sound

(8) In his everyday life, man is aware of a multitude of sounds originating about him. These sounds may be in the form of voices as people talk to each other, or they may range from harsh, ear-splitting noises to the pleasant sound of one's favorite music. In all cases, though, sound waves have their origin in vibrating matter. At this point several basic facts about sound may be stated. In order for a human to hear, three things must be present:

(*a*) A vibrating body.

(*b*) A transmitting medium (this must be some form of matter).

(*c*) The ear, which receives the sound waves and converts them to impulses the brain can interpret.

(9) Of the three essentials for sound, the *transmitting* medium is the one most altered in diving. Sound does not behave the same way in air as it does in other gases or in water. For example, the speed at which sound travels in air at standard conditions is about 1,090 feet per second. However, in water it travels more than four times that fast. Likewise, its speed varies greatly in all the different media capable of transmitting it. Generally speaking, the more dense and elastic the medium, the better the sound can be transmitted through it.

(10) Because sound is readily transmitted through either air or water, it would appear that two divers could talk to each other underwater without difficulty; such is not the case. All but one ten-thousandth of the sound energy is lost when being transmitted from air to water. Hence, if divers are to talk to each other underwater or to hear sounds originating in the air above them, these sounds must originally be very loud.

(11) When a mixture of gases containing any appreciable percentage of *helium* is breathed, the *voice* acquires an unreal sound like that of Walt Disney's Donald Duck. A similar *effect* is also observed when air or other gases are breathed under high pressure. The greater the pressure, the more pronounced the effect becomes, until at great depths it is very difficult to understand what a diver is saying. In the case of helium, it is believed the effect is due to the higher speed of sound in this gas and the consequent effect on the resonating quality of the respiratory air spaces which control the sound of the voice.

Heat

(12) Heat is another form of energy. It is closely related to temperature but must be distinguished from it, because different substances do not necessarily contain the same amount of heat energy even though their temperatures are the same. *Temperature* is measured in degrees, usually Fahrenheit or centigrade. Heat is measured in Btu's (British thermal units), calories, or kilogram-calories. One Btu is the amount of heat required to raise the temperature of 1 pound of water 1° Fahrenheit. A calorie is the amount of heat required to raise the temperature of a gram of water 1° centigrade, and a kilogram-calorie is the corresponding amount of heat for a kilogram (1,000 grams) of water. The difference between heat and temperature is illustrated by the fact that a cubic foot of heated air would melt far less ice than would a cubic foot of water heated to the same temperature. The water obviously contains much more heat energy than does the air, and this difference in energy is not due to the fact that the water weighs more. A cubic foot of helium requires far more heat to warm it 1° than does a cubic foot of air, and this is true even though the helium weighs less than air.

Heat Transfer

(13) Heat is transmitted from one place to another in one of three ways:

(*a*) *Conduction* is the direct transmission of heat from molecule to molecule through a substance or through materials which are in contact with each other. An unprotected diver loses heat to the water around him mainly by direct conduction through his skin.

(*b*) *Convection* is the transmission of heat by the movement of a heated gas or fluid. If a diver were sitting in a tank of water in a cold room, he would lose heat to his surroundings not only by direct conduction through the water, but also by movement of the water (called convection currents) produced in the following way: The water next to his body, warmed by conduction, would expand slightly and be lighter than the surrounding water. It would therefore rise; but on reaching the top and walls of the tank, it would lose heat to the room, contract, and sink to be warmed again.

(*c*) *Radiation* is the transmission of heat by invisible waves which are not unlike radio waves. Every warm object puts out such waves; if an object is hot enough, it will also produce similar waves which we recognize as light. Although a diver will lose some heat by radiation, the amount is very small compared with the loss by conduction.

(14) The rate of heat transfer by conduction depends both on the difference in temperature between the warm object and its surroundings and on the *conductivity* of the materials concerned. Conductivity refers to the ease with which a material transmits heat by conduction. If a material of low conductivity is placed between the warm object and the surroundings, the object is said to be *insulated*. In general, a substance that has little ability to contain heat has low conductivity and makes a good insulator. Water is an extremely poor insulator, while air conducts heat poorly and makes a good insulator. Helium, on the other hand, is a poor insulator. The *insulation* provided by wool clothing, foam materials, and the like, is because they place a layer of air between the body and its surroundings and confine the air in such a way that convection currents cannot be set up.

(15) *Body* temperature is normally 98.6° F (37° C), and it cannot vary more than a few degrees from this without serious results. The body continually produces heat. On dry land, it loses heat to the air by the three methods of transfer mentioned above, plus evaporation of water from the lungs and skin. As was indicated, only *conduction* is of much importance *under water*. The mechanisms by which the body controls its temperature are discussed in section 1.3 describing the effects of temperature.

(16) If an unclad diver is in water colder than about 70° F, the temperature difference and the high conductivity of water will cause heat to be lost faster than his body can produce it, and he will chill. Some kind of protection must be provided. If the water is not colder than about 60° F, a snug-fitting suit of woolen underwear may suffice. This underwear does not provide much *insulation* in the usual sense, but it traps a layer of water next to the body. When this water is warmed by the body, the temperature difference is decreased, and much less heat is lost than when the body is continually bathed by fresh masses of *cold water*. In colder water, actual insulation with a dead-air space must be provided. This is done either by wearing woolen underwear under a watertight suit or by using a "wetsuit" of unicellular foam material that does not lose insulating value even though its surfaces are wet.

1.2.10 UNITS OF MEASUREMENT

(1) Distances, pressures, or volumes can be expressed in various *units*. For example, length can be measured in inches, feet, yards, or miles; one uses the unit of most convenient size for what he is measuring. Having different units becomes inconvenient when a measurement must be converted from one unit to another. The situation is complicated by the fact that there is more than one system of units. English-speaking countries use the system of feet, pounds, pounds per square inch, etc.; while the rest of the world uses the *metric* system of meters, grams, etc. Because it is more logical, more widely understood, and easier to handle, the metric system is used for most scientific measurements.

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The Metric System

(2) The metric system is so widely used that a diver sooner or later will come in contact with it. He should understand how it works and should be able to convert from metric to English units, and vice versa. (Tables 1–2 through 1–5, "Tables of Conversion Factors," provide information for this purpose.)

(3) The metric system has an advantage in that all its units are so related that it is not necessary to use calculations when changing from one metric unit to another. This system is based on decimals, as is the American system of money. An American can express a sum of money either in dollars or in cents simply by moving the decimal point. In the same way, the metric system changes one of its units of measurement to another by moving the decimal point, rather than by the lengthy calculations necessary in the U.S. system.

(*a*) *Length.*—The principal metric unit of length is the *meter* (39.37 inches). For measuring smaller lengths, *millimeters* (mm) or *centimeters* (cm) are used:

1 meter =100 centimeters (cm)
=1,000 millimeters (mm)
1 millimeter=0.10 (one-tenth) centimeter
=0.001 (one-thousandth) meter

For longer distances, the metric system uses the *kilometer* (about six-tenths of a mile).

1 kilometer=1,000 meters
1 meter =0.001 kilometer

(*b*) *Area.*—The metric system uses its units of length squared to measure area, as does the U.S. system. As in converting from one metric unit of length to another, converting units of area is merely a matter of moving the decimal point. In this case, it is moved twice as many places as in measures of length. For example, 1.0 meter=100.0 cm; 1.0 square meter=10,000 square centimeters. (Compare this operation with that of multiplying by 144 to convert from square feet to square inches.)

(*c*) *Volume* or *capacity.*—Volumes can be expressed as metric units of length cubed. Conversion of volumes from one metric unit to another requires only moving the decimal point three times as many places as in converting units of length. For example, 1,662 cubic millimeters equals 1.662 cubic centimeters. (To convert cubic inches to cubic feet, you would have to divide by 1,728 (12×12×12).) In addition to cubic feet and the like, the U.S. system also uses pints and quarts, etc., as units of volume or capacity. There is no simple relationship between these units of volume and the cubic measurements, so conversion involves a lot of odd numbers. The metric system uses the liter (about the same as a quart) for similar purposes, but a liter equals 1,000 cubic centimeters (cc) or 0.001 cubic meter (m^3), so conversions are simple.

1 liter=1,000 cubic centimeters
=0.001 cubic meter

(*d*) *Weight.*—The gram (g) is the basic metric unit of weight. It is defined as the weight of 1 cubic centimeter of water. For larger weights, the kilogram (kg) is the usual unit. It is equal to 1,000 gm, or the weight of a liter of water (about 2.2 pounds). For very small weights, the milligram (mg) is used (one-thousandth of a gram).

1 gram =0.001 kilogram
=1,000 milligrams
1 kilogram =1,000 grams
1 milligram=0.001 gram

(*e*) *Pressure.*—Instead of using pounds per square inch, the metric system *measures* pressure in terms of *grams or kilograms per square centimeter.* One kilogram per square centimeter (kg/cm^2) is equal to 14.22 psi. A pressure of 1 gram per square centimeter is equal to a manometer reading of 1 centimeter of water because, by definition, a gram is the weight of 1 cubic centimeter of (fresh) water. Consequently, a pressure of 1 kg/cm^2 is equal to that exerted by a column of water 1,000 centimeters, or 10 meters, high. It is thus the gage pressure at a depth of 10 meters in fresh water (10 meters=32.8 feet). Note that 1 kg/cm^2 is very close to 1 atmosphere: 14.22 psi, or about 32 feet of sea water.

1 kg/cm^2=1,000 gm/cm^2
=1,000 cm H_2O
=10 meters H_2O
=(approx.) 1 atmosphere

(4) Notice that the decimal basis of the metric system and the relationships between that system's units of length, area, volume, weight, and pressure make many things simpler than they are in the U.S. system. As a result, even the process of converting from a U.S. to a metric unit of measurement, and vice versa, is fairly simple.

(*a*) If one knows that 1 inch equals 2.54 centimeters, he also knows that it equals 25.4 millimeters and 0.0254 meter. If he knows that a liter of water weighs 1 kilogram or about 2.2 pounds, he also knows that 1 centimeter of water weighs one-thousandth of that, or 0.0022 pound, and that a cubic meter of water weighs a thousand times 2.2, or 2,200 pounds.

(*b*) In the following problem, with all the units in the metric system, consider how many more steps and how much more arithmetic would be required to calculate the answer if the U.S. system had been used: Several gas cylinders have an internal volume of 12 liters, charged to 150 kg/cm² (gage). A 165-kg anchor must be raised off the bottom in 50 meters of water using a collapsible pontoon which weighs 45 kg. How many cylinders will be needed to inflate the pontoon enough to start raising the anchor? Solution: At least 210 (165+45) kg of buoyancy are needed to offset the weight of anchor and pontoon. The pressure at that depth is about 1 atmosphere per 10 meters, or 5 atmospheres (gage)+1=6 atmospheres absolute. Each cylinder will deliver one volume (12 liters) of free air at the surface for each atmosphere of pressure released. It will deliver one-sixth of that volume, or 2 liters, at the depth concerned. Because the cylinder pressure is 145 (150−5) kg/cm² (or about 145 atm) above the depth pressure, each cylinder should deliver about 290 (145×2) liters at depth. This would yield about 290 kg of buoyancy, so one cylinder should be sufficient.

Temperature Scales

(5) Countries using the English or the U.S. system of weights and *measures* generally employ the Fahrenheit temperature scale. Countries that use the metric system, and most scientific laboratories, use the *centigrade* scale instead. The centigrade scale uses the temperature of melting ice (32° F) as zero and the temperature of boiling water (212° F) as 100°. The Fahrenheit scale is humorously said to have been based partly on the body temperature of a certain sick cow (100° F).

(6) The rules for converting from one temperature scale to the other can be summed up by these formulas and statements:

(*a*) To convert Fahrenheit to centigrade:
Formula:

$$°C=\frac{5}{9}\times(°F-32)$$

Steps:
1. Subtract 32 from the Fahrenheit reading.
2. Multiply the result by 5/9.

(*b*) To convert centigrade to Fahrenheit:
Formula:

$$°F=\left(\frac{9}{5}\times°C\right)+32$$

Steps:
1. Multiply the centigrade reading by 9/5.
2. Add 32 to the result.

(*c*) Procedures:

1. When adding or subtracting 32, do it algebraically: In the first step of the °F to °C formula, if the original F temperature is positive (above zero) simply subtract 32; if it is minus (below zero), add 32 and keep the minus sign. In the second step of converting °C to °F, if the value is positive (above zero), simply add 32; if it is negative (minus) and greater than 32, subtract 32 from it and keep the minus sign; if it is negative but less than 32, find the difference and discard the minus sign.

2. If the value you multiply by 9/5 or 5/9 has a minus sign, the product is also a negative value, so keep the minus sign.

3. Instead of multiplying by 9/5, you can multiply by 1.8 if you prefer. Instead of multiplying by 5/9, you can divide by 1.8 or multiply by 0.556.

(7) If it is difficult to remember which of these formulas to use and how they work, try considering it this way: The freezing point of water is 0° C or 32° F. The boiling point is 100° C or 212° F. Therefore, the range from the

freezing point to the boiling point of water is 100−0=100° on the centigrade scale and 212−32=180° of the Fahrenheit scale. Therefore, it must take 180/100, or 9/5, or 1.8 times as many Fahrenheit degrees to cover any part of the scale as it does centigrade degrees. In other words, a Fahrenheit degree is 100/180, or 5/9, or 0.556 the "size" of a centigrade degree; and a centigrade degree is 9/5, or 1.8 times the size of a Fahrenheit degree. If this 100 versus 180 relationship is kept in mind and if it is remembered that the freezing point is zero degrees centigrade and +32 degrees Fahrenheit, the conversion process becomes fairly simple and does not have to be memorized by rote. The basic idea is first to calculate how many degrees *above or below freezing* a temperature reading is on its own scale. Then calculate how many degrees on the other scale would cover this same span. Finally, consider where freezing is on this scale, and adjust the value if necessary.

(*a*) For example, convert normal body temperature (98.6° F) from Fahrenheit to centigrade.

1. 98.6 is 98.6−32=66.6° F above freezing.

2. 5/9×66.6=37° C above freezing.

3. Freezing is 0° C, so 37° C is the final answer.

(*b*) Another example: Convert 25° C to Fahrenheit.

1. Since 0° C=freezing, 25° C is 25 degrees above freezing.

2. 9/5×25=45° F above freezing.

3. Freezing=32° F, so the final answer is 45+32=77° F.

(*c*) The same principles apply even if both readings are below zero. Convert −10° F to centigrade:

1. Since freezing is 32° F, −10° F is 32+10=42° F below freezing.

2. 42×5/9=23.3° C below freezing.

3. Since freezing is 0° C, −23.3° C is the final answer. (Note the minus.)

(*d*) The same process works when one reading is below zero and the other is not: Convert −10° C to Fahrenheit:

1. −10° C is 10 degrees below freezing.

2. 10×9/5 (or 10×1.8)=18° F below freezing.

3. Since freezing is 32° F, 18° F below freezing=32−18=14° F.

Absolute Temperature

(8) Temperature must be converted to *absolute* when working with the gas laws. This involves the idea of absolute zero—the lowest temperature which could possibly be reached. This temperature is assumed to be 273.13° below zero on the centigrade scale or 459.72° below zero on the Fahrenheit scale. Absolute temperatures are used for setting up ratios between T_1 and T_2 temperatures in gas-law calculations. Therefore, it does not matter whether the figures are in centigrade or Fahrenheit units as long as the *same* scale is used for all temperatures in each calculation. Because the absolute zero is so large, it is usually permissible to round the value to the nearest whole number: add 273 to the temperature if using centigrade units; add 460 to the temperature if using Fahrenheit units.

Barometric Pressure

(9) Barometric pressure is usually *measured* in inches or millimeters of mercury. Although we now have mechanical (aneroid) barometers, the standard instrument is still a vertical glass tube with its upper end closed and its open lower end immersed in cup of mercury. The atmospheric pressure is measured by the height of the column of mercury it is able to support in the tube, and this height is read directly in units of length. Readings can be converted by the usual method of converting inches to millimeters and vice versa (1 inch=25.4 mm). When the barometric pressure is employed in calculations related to gas laws or gas analysis, it is usually used to establish the ratio between P_1 and P_2 pressures or between existing pressure and standard pressure (760 mm Hg or 29.92 in. Hg). Either inches or millimeters can be used for this purpose as long as the same units are used throughout a given calculation.

(10) Some barometers are calibrated in *millibars*. Usually they are also provided with an inch scale, and this should be used in preference for calculations related to diving. If this scale is not provided, the millibar reading can be used directly in most calculations, just as it is possible to use either inches or millimeters of mercury. Standard pressure (equivalent to 760

mm Hg or 29.92 in. Hg) is 1013.3 on the millibar scale.

(11) It is rarely necessary to convert barometric readings from inches or millimeters of mercury to psi or kg/cm². For most calculations involving higher pressures, 14.7 psi or 1.033 kg/cm² are sufficiently accurate approximations of barometric pressure. In some cases, it is permissible to round these figures even further: 15 psi or 1.0 kg/cm². However, if such conversions are necessary, refer to tables 1–2 to 1–5 for the appropriate factors.

Use of Conversion Factors

(12) Tables 1–2 to 1–5 provide most factors likely to be required in diving for converting measures of length, area, volume or capacity, weight, or pressure from one unit to another. They are presented in four groups: factors for converting from one U.S. unit to another (from U.S. to U.S.), from metric to metric, from U.S. to metric, and from metric to U.S. Not every conversion is given because many of them are seldom used and can be readily derived from other factors. For example, no factor is listed for converting miles to meters; but the mile-to-kilometer and kilometer-to-meter factors are listed.

(13) In most cases, the desired conversion can be directly made by multiplying the original measurement by the appropriate factor from the table. For example, if one wishes to convert a length of 9 inches into equivalent number of centimeters, he finds *1 inch* in the U.S.-to-metric table and notes that it equals 2.54 cm. He then multiplies 9 by 2.54 to obtain the answer. Where no direct factor is given, one of the values must be converted into another unit either before or after the nearest usable factor is employed. For example, no factor is listed for converting 0.96 kilometer directly into feet, but the kilometer-mile and meter-foot factors are given. Because conversions within the metric system require only moving the decimal point, it is usually simpler to make the secondary conversion in the metric units. In this example, it is much easier to change 0.96 km to 960 meters and use the meter-foot factor than to convert kilometers to miles and multiply by 5.280.

(14) If conversions must be made frequently, it is worthwhile to learn the use of a slide rule. A single setting on the rule permits the rapid reading of a whole series of converted values. If a particular conversion has to be made repeatedly, it may be profitable to make a table or graph of equivalent values. Unless great accuracy is required, a graph is the simplest scheme: To convert from psi to kg/cm², for example, psi is marked off on the horizontal axis and kg/cm² on the vertical axis of the graph paper. A few equivalent values are then calculated, plotted on the graph, and a straight line is drawn to connect the points. To convert psi to kg/cm², the pressure in psi is found on the horizontal scale, the point where this hits the straight line is noted, and then the location of this point on the kg/cm² scale is found. Using such a graph is as simple as reading a gage or a thermometer, and the same graph can be used for conversions in either direction.

SECTION 1.3 UNDERWATER PHYSIOLOGY

1.3.1 MAN AND HIS ENVIRONMENT

(1) In many ways the body is like a machine, but its abilities are so complicated and so remarkable that no manmade mechanism has ever come close to equaling it. The body is made up of living cells—many billions of them—so small that they can be seen only under a microscope. Like all animal matter, these cells burn food materials by oxidation and produce carbon dioxide, water, waste materials, and heat. Such cells can live only if they are kept supplied with the food, oxygen, and chemicals they need; if carbon dioxide and other wastes are carried away; and if the gas pressures, acidity, and temperature of their surroundings are kept within close tolerances. Managing all these things to keep body cells alive in a test tube is a complicated and demanding laboratory operation. But the billions of cells working together in the body do all these jobs themselves—and not only stay alive but also have ability and energy left for work, play, learning, reproduction, and all other functions that make up human life.

(2) The cells of the body are of many different types and are organized into numerous kinds of tissue. The tissues in turn are formed into the many parts, organs, and systems, the interworking of which makes life possible for the whole organism. Every cell of every part of the body is surrounded by tissue fluids. These fluids make up the cell's immediate surroundings and transmit, in dissolved form, the materials the cell needs for its life and for the end products it forms. It is in this internal environment of the body that conditions must be kept constant for the cells to live and function normally.

(3) Even when conditions in the outside surroundings—the external environment—are nearly perfect and require little compensation by the body, maintaining the proper internal environment still requires the work of almost all the organs and systems. The heart pumps blood to all parts of the body, and the tissue fluids everywhere exchange dissolved materials and gases with the blood. The lungs keep the blood supplied with oxygen and cleared of excess carbon dioxide by the process of breathing. The digestive system provides food for the blood to carry to the tissues. The kidneys clear the blood of the waste materials it takes up from the tissue fluids. The excess heat produced by the body is lost when the blood reaches the skin, which is cooled by contact with air and by evaporation of fluid from the sweat glands. These are only a very few of the many complex processes that operate all the time to maintain the internal environment and life itself.

(4) The science of *physiology* is concerned with these functions and processes of the living body: how they operate under normal and abnormal conditions, what changes take place in various diseases, and how the body tries to keep the internal environment constant in the face of external changes and unfavorable conditions. Physiology is also naturally concerned with methods by which the body's compensating processes can be helped when they alone cannot cope with the external environment.

(5) Some of the processes of life and adjustment occur almost automatically, but most of them are controlled by the brain and nervous system and various glands. In most cases, the process and its control take place without any awareness on the individual's part. However, some functions require conscious thought and action. Actions such as eating when one is hungry and putting on a coat when one gets cold are important conscious aspects of the job of keeping conditions constant in the internal environment. The body can adjust automatically to many unfavorable conditions in the external environment; but there are many places in the world where, unless this adjustment is aided by such conscious action as the building and heating of houses, people would not be able to live

at all. When he is diving or high-altitude flying, a man faces a *markedly* abnormal environment. Under such conditions, he can stay alive and do useful work only because he has *special knowledge* and *special equipment* to help his body's adjustment processes maintain his internal environment.

(6) As far as breathing is concerned, the body has no way at all of adapting itself to a *watery* external environment without artificial aids. If a man wants to stay under water for more than a few minutes, he must somehow take his atmosphere with him, and diving (as we know it today) remained impossible until reliable ways of doing this were developed. The body also lacks effective ways of compensating for many of the effects of increased pressure at depth and can do little to keep its internal environment from being upset by them. Such effects set definite limits to what a diver can do, and they can give rise to serious accidents. Safe diving becomes possible only through a knowledge of what physiological effects are produced, how much of a limit they impose, and how some of them can be avoided or reduced. A diver's knowledge of these things can be as important as his own good health and the condition of his gear.

(7) The purpose of this section on *underwater physiology* is to provide the necessary background information concerning the parts, systems, and physiological processes that are especially important in diving. To achieve this purpose requires first a brief discourse on anatomy (the way the body is constructed) and then the discussion of *physiology* (how living matter functions). After discussing these topics, the chapter deals with what a diver needs to know about the effects diving can have on the structure and function of the body and what can (or cannot) be done about these effects.

(8) Most of the problems and accidents discussed below are summarized in section 1.6. This section includes indications of situations where accidents are likely to occur; concise lists of symptoms; and steps useful in the prevention, detection, and handling of accidents. Also, treatment of various accidents is covered in greater detail in section 1.6. A number of hazards not covered in here, especially those involving a mechanical injury or a combination of several physiological problems, are also discussed in section 1.6. Other environmental hazards are described in appendix A.

1.3.2 RESPIRATION AND CIRCULATION

Importance

(1) Every cell in the body must obtain energy in order to maintain its life, its growth, and its particular function. The cells obtain this energy from chemical reactions which take place inside them. The reactions are complicated; but the main result is a slow, flameless burning (oxidation) of food materials. Like the burning of any material, this oxidation requires not only fuel but also oxygen; carbon dioxide, water, and heat are produced by it. The process of oxidizing food is called *metabolism*. The use of oxygen and the production of carbon dioxide (and the exchange of these gases with the surroundings) is called *respiration*.

(2) Only a few of the body's billions of cells are close enough to the body's surface to have any chance of obtaining oxygen by direct diffusion from the air, or of getting rid of carbon dioxide by the same method. To do this, the cells would have to be spread out in a thin layer over a very large surface. Instead, the exchange of gases takes place via the circulating blood. The blood is exposed to air over a large diffusing surface when it passes through the lungs. When the blood reaches the tissues, the small vessels there provide another large surface where the blood and tissue fluids are in close contact. Gases diffuse readily at both ends of the circuit, and the blood itself has the remarkable ability to carry both oxygen and carbon dioxide. This system normally works so well that even the deepest cells of the body can obtain oxygen and get rid of excess carbon dioxide almost as readily as if they were completely surrounded by air.

(3) If the membrane surface where blood and air come close together were simply an exposed sheet of tissue like the skin, natural air currents would keep fresh air in contact with it. This membrane surface is actually many times larger than the skin area, and is folded and compressed into the small space of the lungs

and protected inside the bony cage of the chest. This compression makes it necessary to move air in and out of the space continually, and this is why man has to *breathe*. The process of breathing and the exchange of gases in the lungs is sometimes called *external respiration* to distinguish it from the use, production, and exchange of gases that take place in the tissues (*internal respiration*).

Steps in the Process of Respiration

(4) Notice that the whole process of respiration includes six important phases:

(*a*) Breathing, or ventilation of the lungs.

(*b*) The exchange of gases between blood and air in the lungs.

(*c*) The transportation of gases by the blood.

(*d*) The exchange of gases between the blood and tissue fluids.

(*e*) The exchange of gases between the tissue fluids and the cells.

(*f*) The use and production of gases by the cells (metabolism).

(5) If any one of these processes stops or is seriously hindered, the cells concerned can no longer function normally or even survive for any length of time. Those in the brain tissue, for example, will stop working almost immediately and will either die or be permanently injured in a few minutes after their supply of oxygen is completely cut off. The respiratory and circulatory *systems* that carry on these processes are of vital importance every minute of a man's life. They are also particularly involved in many of the physiological effects caused by being under water.

1.3.3 THE CIRCULATORY SYSTEM

Anatomy

(1) The very large surface areas required for ample diffusion of gases in the lungs and in the tissues are provided by the thin walls of extremely small blood vessels called *capillaries*. Every part of the body is completely interwoven with intricate networks (or "beds") of capillaries. In the lungs, these capillaries surround the tiny air sacs so that the blood they carry can be exposed to air. In the tissues and organs, no cell is more than a fraction of an inch away from a capillary which can supply its needs by diffusion through the tissue fluids that surround both the cells and the capillaries.

(2) The circulatory system as a whole is a closed system of tubes which includes the *lung capillaries*, the *tissue capillaries*, the *heart*, the *arteries* and the *veins*. The heart is the muscular pump which propels the blood throughout this system. The arteries are the vessels which carry blood from the heart to the capillaries, and the veins are the vessels which return blood from the capillaries to the heart. Both the arteries and veins branch and rebranch many times very much like a tree. The "trunks" near the heart are about the diameter of a man's thumb. The smallest arterial and venous "twigs" in the tissues are so small that you need a microscope to see them. Capillaries provide the connections which let blood flow from the smallest branch arteries into the smallest veins.

The Blood Vessels

(3) Blood in the arteries is under considerable pressure, so these vessels must be tough and strong. Just as an air hose has layers of rubber to seal it and layers of cord or fabric to give it strength, so is an artery made of layers of different kinds of tissue. Layers of elastic fibers give the arteries both strength and the ability to increase and decrease their diameter with changes in pressure. This ability helps keep the pressure fairly constant, maintaining it between pump strokes and thus tending to smooth out the pulsations in much the same way that a volume tank does in an air system. The arteries also contain a layer of muscle cells that are controlled by the nervous system and by certain substances the body produces. When these muscles contract or relax, they change the diameter of the artery and can influence both the flow of blood to a particular place and the pressure in the system as a whole. The arteries are thus not only the supply hoses but also the control valves of circulation. Veins are under little pressure and do not need to control flow, so they are thin and weak compared to the arteries. The capillaries consist of only a single layer of thin cells like those that make up the inner lining of the larger vessels.

(4) Although it forms one continuous system of tubes with the same blood flowing throughout, the circulatory system actually consists of

two circuits. One of these (the pulmonary circuit) serves the lung capillaries, while the other (the systemic circuit) serves the tissue capillaries. Each circuit has its own arteries and veins and its own half of the heart for a pump. Figures 1-20 and 1-21 show the arrangement

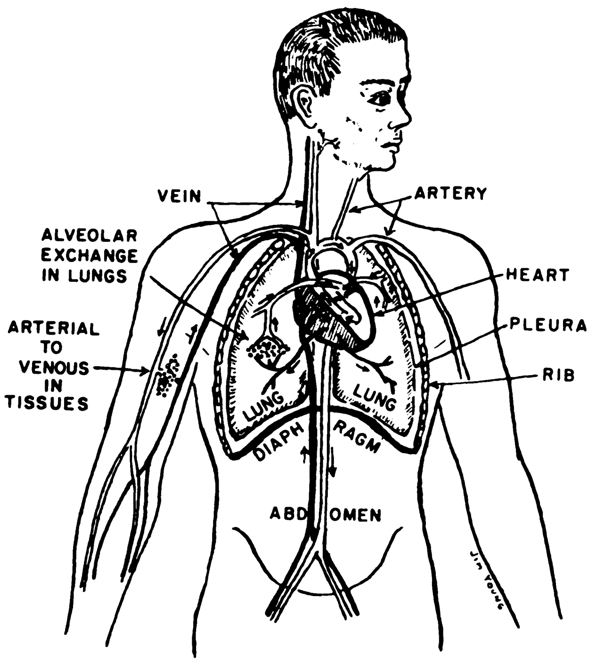

FIGURE 1-20.—Circulatory system.

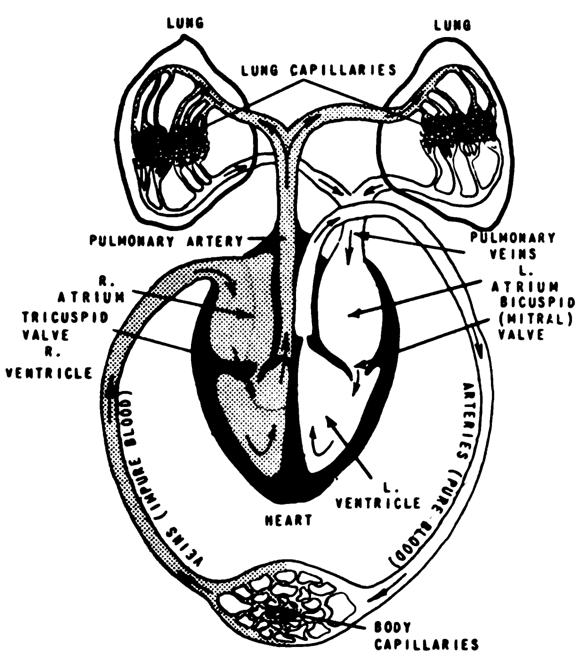

FIGURE 1-21.—Circulatory system in detail.

of the system. In each complete cycle, blood passes first through one circuit and then through the other; it thus goes through the heart twice in each complete cycle.

The Heart

(5) The heart is about the size of a closed fist. It is located in the front and left center of the chest cavity between the right and left lungs, with much of it lying directly behind the breast bone (fig. 1-22). The heart is hollow and

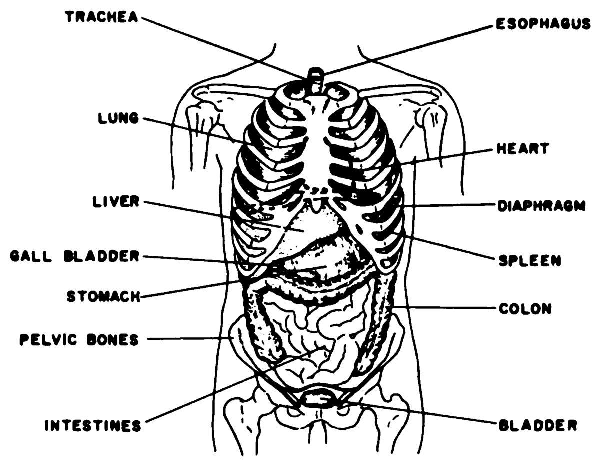

FIGURE 1-22.—Chest and abdominal organs.

is almost entirely made up of muscle tissue which forms its walls and provides the pumping action. The interior of the heart is divided lengthwise into two sections which have no direct connection with each other. The left half is the pump for the systemic circuit, while the right half belongs to the pulmonary circuit. Each half is divided into an upper chamber (*atrium*) which receives blood from the veins of its circuit, and a lower chamber (*ventricle*) which takes blood from the atrium and pumps it into the corresponding main artery. Because the ventricles do most of the pumping, they have the thickest, most muscular walls.

(6) Like most pumps, the heart has *check valves* to keep the flow going in the right direction and to prevent backflow between strokes. There is a valve between each atrium and ventricle and another at the entrance to the main artery on each side. When the heart contracts, the valve between the atrium and ventricle keeps blood from being forced back into the

atrium. When the heart relaxes to refill, the valve between the artery and the ventricle prevents backflow and holds pressure in the artery.

The Path of a Drop of Blood

(7) To see how this system operates, look at figures 1–20 or 1–21 and consider the path a drop of blood follows and what happens to it on its way. A drop of blood leaving a capillary in the right biceps muscle has lost most of its oxygen and is loaded with carbon dioxide. The drop flows first into larger and larger veins until it reaches the main vein in the upper chest (the superior vena cava). From there it flows into the right atrium and through the tricuspid valve into the right ventricle. The next contraction (systole) of the heart forces it through the pulmonic valve into the pulmonary artery. The drop of blood then finds its way through the arterial branchings of the lungs into one of the pulmonary capillaries; here it comes in contact with air. By diffusion, it loses its excess carbon dioxide and takes up a fresh load of oxygen. Then it returns to the heart via the pulmonary venous system and enters the left atrium. The next relaxation of the heart (diastole) finds it going through the mitral valve into the left ventricle. Next it is pumped through the aortic valve into the main artery (the aorta) of the systemic circuit. It then follows one of the main branches of the aorta and again finds itself in a tissue capillary giving up its oxygen and taking up carbon dioxide. It is now ready for another trip to the lungs and back again. On its next return, the same drop of blood may go through the tissue capillaries of the liver or intestines to pick up food materials, through those of the kidneys to drop off wastes, or to the skin capillaries to be cooled.

The Blood

(8) An average man's body contains about 6 liters of blood. (*Note:* In physiology, almost all measurements are made in the metric system. The liter is the usual unit of volume. One liter equals just slightly more than 1 quart: 1.057 quarts.) If the blood were only a simple fluid like water or a saline solution, it could perform only a few of its vital functions and would almost completely fail in the respiratory job of transporting oxygen and carbon dioxide. Only a small fraction of the necessary amounts of these gases could be carried in simple solution in the fluid. Oxygen is carried mainly in the red corpuscles of the blood. These are extremely small dish-shaped cells; there are about 5 million of them in every cubic millimeter of blood, and over 300 million in an average-sized drop. These corpuscles are able to carry oxygen because they contain *hemoglobin.* This is a complicated chemical compound which contains iron. It can form a loose chemical combination with oxygen, absorbing it almost as a sponge soaks up water. When hemoglobin has a full load of oxygen, its color is bright red. As it loses oxygen, it becomes increasingly bluish in color. Whether the hemoglobin gains or loses oxygen depends mainly upon the partial pressure of the oxygen to which it is exposed. At the normal partial pressure of oxygen in the lungs, the hemoglobin takes up about 98 percent of the total amount of oxygen it can carry. Because the cells are using oxygen, the partial pressure (tension) in the tissues is much lower, and the hemoglobin therefore gives up much of its oxygen in the tissue capillaries.

(9) When carbon dioxide dissolves in water, it forms carbonic acid (this is what gives carbonated beverages their tang). Even if carbon dioxide could be carried by the blood simply as carbonic acid, this would make the blood far too acid. Therefore, the blood contains substances called buffers which can neutralize acid and permit large amounts of carbon dioxide to be carried without excessive acidity. The hemoglobin plays an important part in transporting carbon dioxide as well as in carrying oxygen. The uptake or loss of carbon dioxide by blood depends mainly upon the partial pressure or tension of that gas in the area where the blood is exposed.

(10) In addition to red cells, the blood contains a smaller number of white blood cells of several kinds. These cells serve a number of functions including fighting infections. The fluid portion of the blood is called *plasma.* It contains a large amount of dissolved material which is essential to life. Those substances concerned with forming blood clots to stop bleeding are among the substances contained in plasma. Without the clotting ability of blood, a man

could bleed to death from even the slightest injury. The fluid portion of blood which remains after a clot is formed is called *serum.*

Flow, Pulse, and Pressure

(11) The amount of blood in a man's body does not change very much under normal conditions, and the majority of that amount is being circulated at all times. However, the rate at which blood is circulated varies greatly depending on the needs of the tissues. If a man is doing hard work, his heart will have to pump several times the volume of blood per minute that it does at rest in order to keep his working muscle cells supplied with the increased amount of oxygen they need and to take away the extra carbon dioxide. Not only does the heart increase its rate of pumping, but it also increases the extent to which it fills with blood before each beat. The man's pulse—the surge of pressure which can be felt in the arteries when the heart contracts—becomes not only faster but also more forceful. The normal average pulse rate is in the neighborhood of 60 to 80 beats per minute. The rate can exceed 150 during hard work. The heart pumps over 4 liters of blood per minute through each circuit when a man is at rest, but a volume of 20 liters per minute would not be extraordinary in hard work. This volume would amount to about 300 gallons in an hour, or twice that if the volume pumped through each circuit is considered!

(12) The *blood pressure* must stay within certain limits. If it is too low, it does not furnish enough driving force to provide a normal flow of blood through the tissues. If it is too high, there is a risk of bursting some of the more delicate arteries. Blood pressure depends both upon the amount of blood the heart is pumping and upon the resistance of the circuit. Both factors are under the control of the nervous system, which can speed or slow the heart and make the muscle layers of the arteries contract or relax to change their diameter. To aid in controlling blood pressure, the body is equipped with two pressure-sensing devices called *carotid sinuses.* These are located in the neck where the main arteries which supply the head (the *carotid arteries*) make their first branching. By means of nerve impulses, these structures keep the brain informed about the pressure so that it can cause the proper adjustments.

(13) The heart rate and artery diameters are also influenced by certain substances like *epinephrine* (adrenalin). This is produced and secreted into the bloodstream by the adrenal glands in response to nerve impulses from the brain. If a man finds himself in an emergency situation, the brain automatically boosts the secretion and circulation of epinephrine, and this promptly readies his circulatory system for the exertion required by "fight or flight." Epinephrine also stimulates the brain. Usually a diver must face his emergencies without being able either to fight or to run, so this reaction may leave his heart racing, his pulse pounding, and his nerves on edge for no useful purpose. However, it may also give him extra strength and endurance if he needs it.

(14) Blood pressure is customarily measured in millimeters of mercury. The normal average pressure for a young man at rest is about 120 mm Hg when the heart is contracting (*systolic pressure*) and about 80 mm Hg when it is between beats (*diastolic pressure*). (100 mm Hg=about 4½ feet of water.) Both pressures are usually measured at the same time and written down together with systolic above and diastolic below (120/80). Both pressures increase considerably during exertion and excitement; but if they remain much higher, this indicates some abnormality of the circulatory system. A certain amount of increase with age is natural because the arteries gradually lose some of their elasticity.

Fainting and Shock

(15) The automatic control of blood pressure is occasionally upset temporarily by an unusual stress, and a highly unpleasant emotion (for example, that brought on by pain or even the sight of an injury) sometimes has this effect. When the control is upset, the blood pressure may fall to the point where not enough blood is able to reach the brain. The resulting hypoxia can cause dizziness, weakness, nausea, paleness, and loss of consciousness. By making the victim crumple to the deck, fainting (the medical word is *syncope*) automatically lowers the head and

lets more blood reach the brain. Consciousness usually returns in a minute or two. "Passing out" or "falling out" can often be avoided by lowering the head, as by sitting down and leaning over. A person who has fainted should be kept stretched out and watched carefully until consciousness and normal color return and until he feels better. Elevating the feet and legs often hastens recovery. In the rare instances where recovery does not occur promptly, the victim should be seen by a medical officer; in the meantime, administering oxygen is advisable. If breathing stops, artificial respiration must of course be given at once.

(16) Occasionally, almost the same reaction occurs when a man stands still in one spot for a long time (especially in hot weather) or very suddenly stops strenuous exertion. In cases like this, a man loses consciousness because the blood forms pools in the lower part of the body and does not flow back to the heart fast enough for the blood pressure to be maintained. Such happenings are very rare in diving (perhaps partly because immersion cancels the effects of gravity on the circulatory system) but they are a serious problem in aviation. Rapid changes in direction at high speed produce centrifugal or G-forces (G stands for gravity) which can pull the flyer's blood to his legs and abdomen and cause syncope or blackout. The aviator's G-suit offsets this effect by applying external pressure to these parts.

(17) *Shock* is a serious condition brought about by injury with hemorrhage, severe burns, or by a number of other conditions which allow the actual loss of blood or blood fluids from the circulatory system. Under these conditions, the body cannot maintain the blood pressure, and serious tissue hypoxia (insufficient oxygen) develops. Unless shock is recognized and treated, death can result from an otherwise nonfatal injury or condition. One clue to its recognition is that the pulse is both very weak and very rapid. (In syncope, the pulse may be extremely feeble, but the rate is usually close to normal.) Treatment of shock requires careful medical attention; and the replacement of the blood volume by giving blood, plasma, or a suitable substitute intravenously is usually required.

1.3.4 RESPIRATION

The Respiratory Apparatus

(1) The essential parts of man's respiratory apparatus are the lungs and the air passages leading into them. The chest wall with its ribs and muscles, the diaphragm, and other muscles taking part in the mechanical phase of respiration make up the accessory apparatus which produces the movement of air. The mechanism of taking fresh air into the lungs (inspiration) and expelling foul air from the lungs (expiration) is diagrammatically shown in figure 1–23. By elevating the ribs and lowering the diaphragm, the volume of the chest cavity is increased. According to Boyle's law, a lower pressure is thus created within the chest space and lungs. To equalize this lowered pressure, fresh air automatically rushes into the lungs. When the ribs are again lowered and the diaphragm rises to its original position, a higher pressure is created within the lungs. This causes the foul air to be expelled. In the human chest cavity, there is no space between the outer lung surfaces and the surrounding chest wall and diaphragm as shown in the figure. The membrane which covers the lung surface is in contact with that which lines the cavity. The only normal separation is a film of fluid which allows the membranes to slide freely over each other. However, if the surface of the lung is accidentally ruptured by a sudden excessive pressure inside the lungs, or if the chest wall is perforated by some external means, air will be pulled in between the membranes when the chest expands. An actual air pocket will then exist between the lung and the chest wall. This condition is known as *pneumothorax* (*pneumo* means air; *thorax*, chest) and may occur as an accident in diving or submarine escape.

(2) The lungs can be thought of as two elastic bags containing millions of little distensible air sacs. These air sacs or alveoli are all connected to the air passages, which branch and rebranch like the twigs of a tree. Air that enters into the main air passages of the lung gains access to the entire surface of all these alveoli. Each alveolus is lined with a thin transparent membrane and is surrounded by a network of very small blood vessels. These vessels—many millions of them—make up the capillary bed of

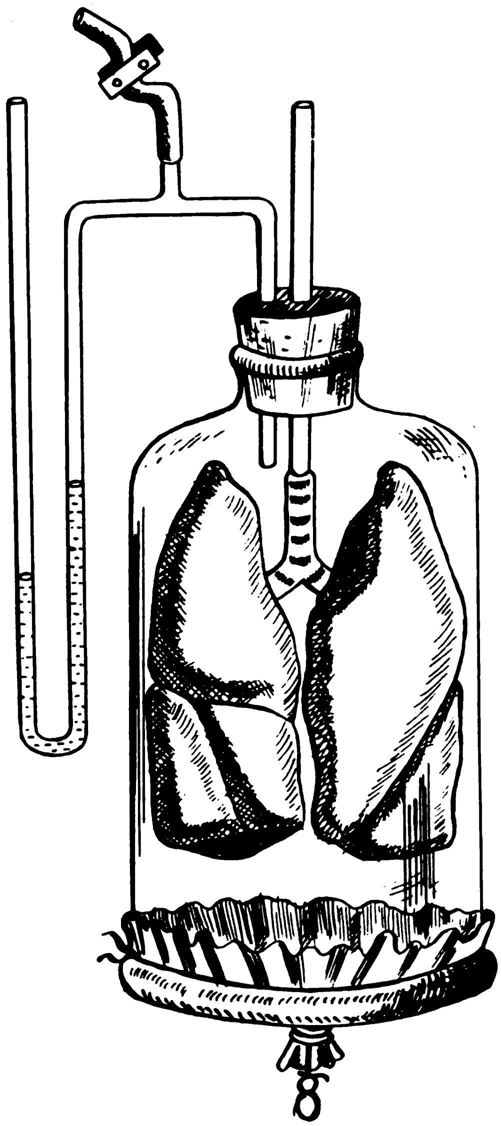

FIGURE 1–23.—Mechanics of breathing: model. Rubber sheet represents diaphragm. Pulling it down enlarges space, reduces pressure in it and thus causes air to enter lungs and expand them. Enlarging container itself (which represents rib cage) would have same effect. (In the actual body there is no air space between lungs and surrounding chest wall and diaphragm.)

the lungs. The total surface area of membrane exposed to the air within the lung is tremendous. If this lining could be stripped from all of the sacs and tubes of both lungs and then inflated, it would form a spherical balloon about 17 feet in diameter. If it were spread out as a continuous flat sheet, it would cover an area 30 feet × 30 feet (approximately one-half the area of a single tennis court). This is about 50 times the surface area of the skin of our bodies. Most of the lung membrane has air on one side of it and blood on the other, and diffusion of gases takes place freely in either direction. It is not surprising that the lungs have a tremendous capacity for exchanging gas between the air and the blood.

Terminology and Definitions

(3) In order to discuss intelligibly the process of *breathing* and the other aspects of the respiratory mechanism that are important in diving, the definitions of some terms are given below:

(*a*) A *respiratory cycle* is one complete breath—an inspiration followed by an expiration, including any pause that may occur between the movements.

(*b*) *Respiratory rate* (or frequency) is the number of complete respiratory cycles that take place in 1 minute. At rest, a normal adult will have a respiratory rate somewhere between 10 and 20 breaths per minute. The rate normally increases during work.

(*c*) *Total lung capacity* is the total volume of air that the lungs can hold when filled to capacity (fig. 1–24). It is normally between 5 and 6 liters. (A liter is about the same as a quart. It is the standard unit of volume in the metric system, which is generally used in physiological measurements.)

(*d*) *Vital capacity* is the greatest volume of air that a man can expel from his lungs after a full inspiration. In other words, it is the greatest volume of air that can be moved in and out of the lungs in a single breath. The average man's vital capacity is between 4 and 5 liters (fig. 1–24).

(*e*) *Tidal volume* is the volume of air moved in and out of the lungs during a single normal respiratory cycle. During a period of rest, the tidal volume generally averages about one-half of a liter. Tidal volume increases considerably during physical exertion. It naturally cannot exceed the vital capacity.

(*f*) *Inspiratory reserve volume* is the amount of air that can be brought in by forcible inspiration after completion of a normal inspiration. It averages about 2½ liters during a period of rest and becomes smaller as the tidal volume increases (fig. 1–24).

(*g*) *Expiratory reserve volume* is the amount of air that can be expelled by forcible expiration at the end of a normal expiration. It normally amounts to about 1 liter during a period of rest and becomes smaller as the tidal volume increases. Note that the sum of the tidal volume and inspiratory and expiratory reserve volumes equals the vital capacity.

(*h*) *Residual volume* is the amount of air that remains in the lungs even after the most forceful expiration. It normally amounts to between 1 and 1½ liters. Note that the sum of the vital capacity plus the residual volume equals the total lung capacity. (All these relationships are shown in fig. 1–24.)

(*i*) *Respiratory minute volume* (*RMV*) is the total amount of air moved in and out of the lungs in a minute. Multiplying the tidal volume times the rate gives the respiratory minute volume. Minute volume varies greatly with the body's activity. It is about 6 liters during a period of complete rest and may be over 100 liters during very heavy work.

(*j*) *Maximal breathing capacity* is the greatest respiratory minute volume a person can produce during a short period of extremely forceful breathing. In healthy young men it may reach as much as 170 liters per minute.

(*k*) *Respiratory dead space* is that part of the respiratory system which has no alveoli and in which little or no exchange of gas between air and blood takes place. It normally amounts to less than 0.2 liter, but becomes larger as the depth of breathing increases. Air that occupies the dead space during each breath does not take part in the active process of breathing. Certain

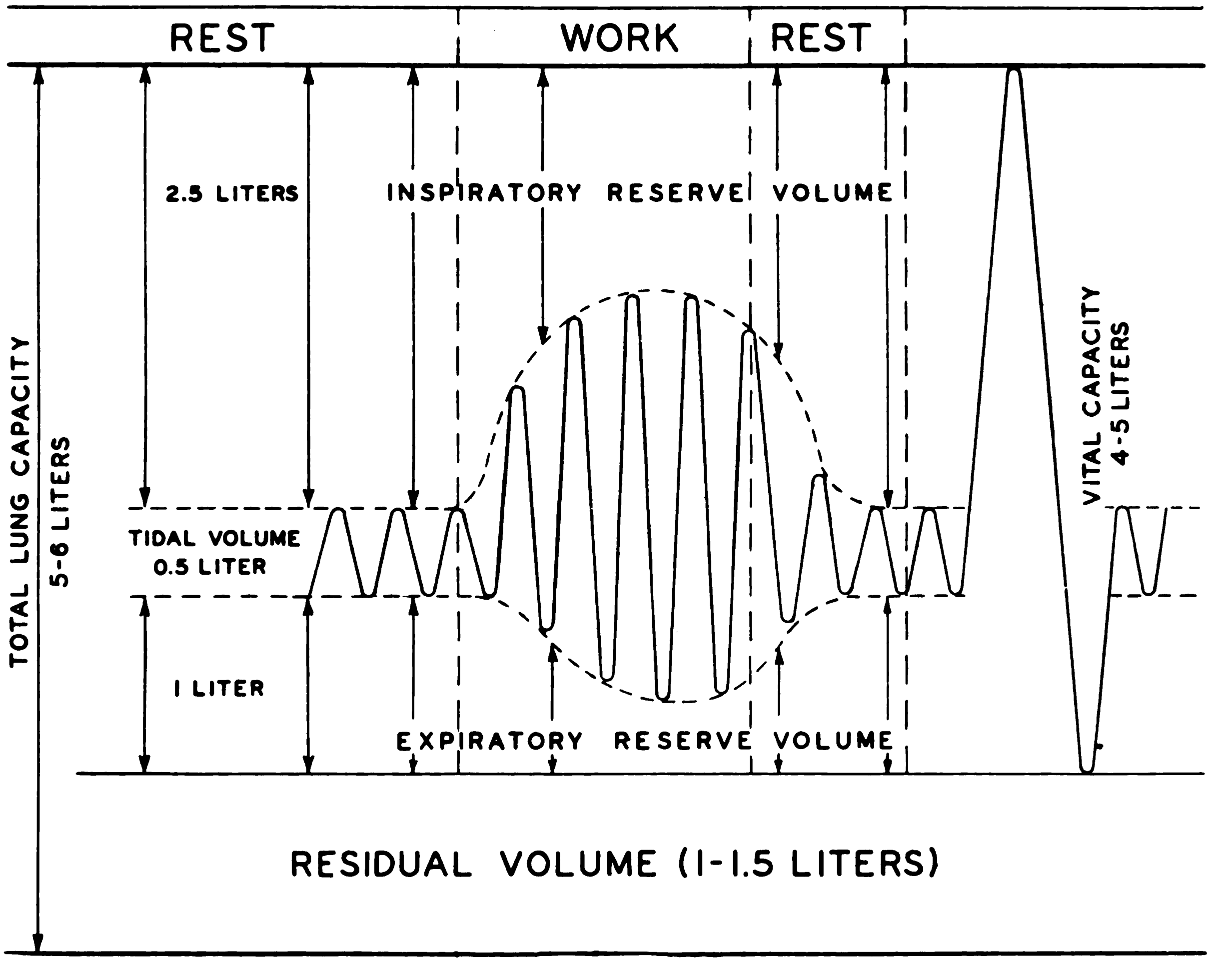

FIGURE 1–24.—Lung volume.

parts of a diver's breathing apparatus can add to the volume of the dead space and thus reduce the proportion of the tidal volume which serves the purpose of respiration (see 1.3.5(35)). To compensate, the diver must increase his tidal volume.

(*l*) *Net alveolar ventilation* refers to that portion of the respiratory minute volume which reaches the alveoli and exchanges gas with the blood. Multiplying the dead space volume by the respiratory rate and subtracting this from the minute volume gives the net alveolar ventilation.

The Respiratory Process

(4) With these definitions as a background, the process of respiration can be explained. The diffusion of gases into a liquid follows Henry's law and Dalton's law. The air we take into our lungs (inspired air) is a mixture of gases which exerts a total pressure at sea level of 14.7 pounds per square inch or 760 millimeters of mercury. (In physiology, pressures are usually expressed in millimeters of mercury rather than pounds per square inch.) Within the alveolar air spaces, the composition of the air (alveolar air) is changed, due to the elimination of carbon dioxide from the blood, the absorption of oxygen by the blood, and the addition of water vapor, which exerts a pressure just like any other gas. The air we breathe out (expired air) has still another composition which represents a mixture of alveolar air and the inspired air which remained in the dead space. Table 1–6 shows the partial pressure exerted by the gases present in each type of air.

(5) The blood in the capillary bed of the lungs is exposed to the gas pressures of alveolar air through the thin membranes of the air sacs and the capillary walls. With this exposure taking place over a vast surface area, the gas pressures of the blood leaving the lungs are approximately equal to those present in alveolar air. Roughly, the arterial gas pressures in millimeters of mercury are 100 mm for oxygen, 40 mm for carbon dioxide, 47 mm for water vapor, and 570 mm for nitrogen. When this arterial blood passes through the capillary network surrounding the cells in the body tissues, it is exposed to and equalizes itself with the gas pressures of the tissues. Some of the blood's oxygen is consumed by the cells, and carbon dioxide is picked up from these cells. Nitrogen and water vapor, being inert, remain unchanged. The partial pressures of oxygen and carbon dioxide differ for arterial and venous blood as shown in table 1–7. Note that blood of arterial quality is carried from the lungs to the heart in the pulmonary *veins*. (Hereafter in this discussion, the terms *arterial* and *venous* will refer to the quality of the blood and not to the kind of vessel through which it is passing.) The values shown in table 1–7 for venous blood rep-

TABLE 1–6.—*Partial pressures of gases in lung air*

Gas (barometer at 760 mm Hg)	Partial pressure in mm Hg [1]		
	Inspired air [2]	Expired air	Alveolar air
Oxygen	158.25	116.2	101.2
Carbon dioxide	.30	28.5	40.0
Nitrogen	596.45	568.3	571.0
Water vapor	5.00	47.0	47.0
Total	760.00	760.0	760.0

[1] These are average figures for a man breathing air at surface. Expired air contains more oxygen and less carbon dioxide than alveolar air because it includes fresh air from respiratory dead space. At depth, carbon dioxide and water vapor pressures remain about the same, whereas others increase in proportion to absolute pressure.

[2] Variable, according to humidity and temperature of inspired air.

TABLE 1–7.—*Partial pressures of gases dissolved in arterial and venous blood*

Gas	Gas tension or partial pressure in mm Hg	
	Arterial blood	Venous blood
Oxygen	100	40
Carbon dioxide	40	46
Water vapor	47	47
Nitrogen	570	570
Total	757	703

resent the approximate partial pressures of gas present within tissue cells when the body is exposed to air at atmospheric pressure. When the venous blood returns to the pulmonary capillaries and becomes exposed to the alveolar air, it becomes arterial blood. Equalization of the partial pressures of gases between the blood and the alveolar air again takes place. Carbon dioxide diffuses from the blood into the alveolar air and CO_2 pressure drops from 46 mm (venous) to 40 mm (arterial). Oxygen is absorbed by the blood from the alveolar air, and O_2 pressure increases from 40 mm (venous) to 100 mm (arterial). With each complete round of circulation the process of gas exchange between lung air and the tissues takes place through the medium of the blood.

Control of Breathing

(6) When a man works, the amount of oxygen he consumes increases markedly, and so does the amount of carbon dioxide he produces. The amount of blood being pumped per minute through the tissues and the lungs increases in proportion to the rate at which these gases must be transported. As a result, more oxygen is taken up from the alveolar air, and more carbon dioxide is delivered to the lungs for disposal. To keep the blood levels where they belong, the *respiratory minute volume* (and hence the *net alveolar ventilation*) must also change in proportion to the man's oxygen consumption and carbon dioxide output. Breathing is controlled by two types of sensing devices (part of the nervous system) and by certain other mechanisms. As a result of the regulatory process and the adjustments caused by these devices, the arterial blood leaving the lungs usually has about the same oxygen and carbon dioxide levels during work that it did during rest. The maximum pumping capacity of a man's heart and respiratory system largely determines the amount of work he can do.

(*a*) The *respiratory center*, a part of the brain itself, is sensitive to the tension of carbon dioxide in the blood. If the tension is too high, the center causes breathing to increase until the normal level is restored. This mechanism is the main one that controls breathing under ordinary conditions.

(*b*) Sensors called *chemoreceptors* are attached to important arteries. The most important of these are the *carotid bodies* (in the neck) and the *aortic bodies* (near the heart). Chemoreceptors are sensitive mainly to the tension of oxygen in the blood; when it gets too low, they send impulses to the respiratory center to increase breathing. Low oxygen tension alone generally does not markedly increase breathing until dangerous levels are reached. However, the part played by the chemoreceptors is evident even in such a nearly normal process as the holding of one's breath (see 1.3.5(41)).

(*c*) Such factors as physical exertion itself influence breathing to an extent not completely explained by the systems just described. Other mechanisms which are less well understood also help regulate breathing, and there are several things about the control of breathing under diving conditions that are simply not known.

Respiratory Quantities

(7) There are many situations in diving in which it is important to have an idea of the amount of oxygen a diver is consuming, how much carbon dioxide he is producing, or how much air he needs in order to ventilate his lungs or his helmet. These factors come into play in determining the adequacy of an air supply for surface-supplied diving, and they are especially important in scuba diving where the diver must carry his breathing medium with him and may or may not be able to carry enough to do a certain job. In mixed-gas apparatus, the probable oxygen consumption is a large factor in determining what mixture will be used, what flow rate will be provided, and what the diver will be able to do (3.6.5). It is seldom possible to measure these quantities during a regular dive or to make precise predictions, but if the nature of the job is known, a satisfactory estimate can usually be made by referring to data from experimental studies.

(8) The amount of work a man is doing is the main thing that determines the respiratory quantities. A man's oxygen consumption is one of the best indications of this work rate, and the other factors are closely related to it. Figure 1–25 shows the results of a study in which oxygen consumption was measured for underwater

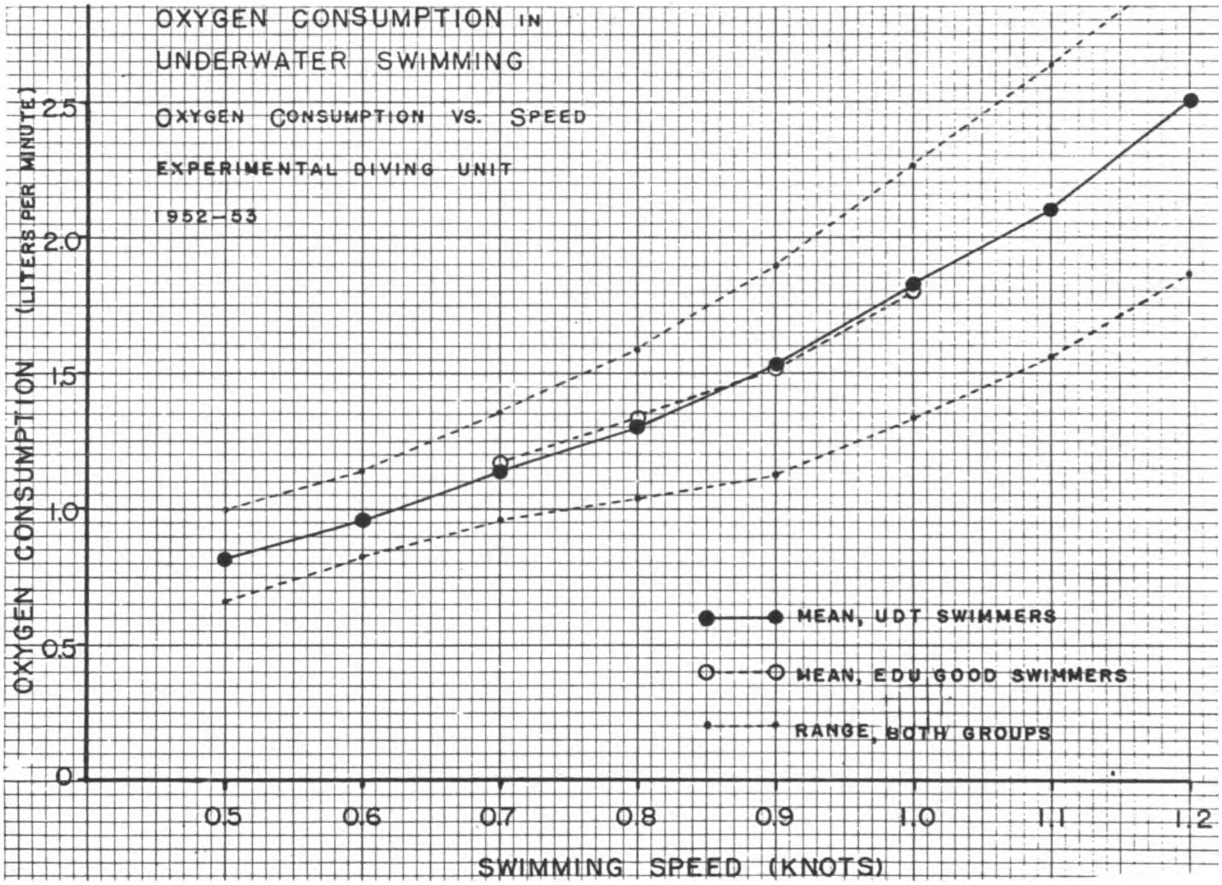

FIGURE 1–25.—Oxygen consumption during underwater swimming.

swimming at various speeds. Table 1–8 gives some comparisons of average oxygen consumption and RMV at various levels of activity on land and under water. Notice that with the body at complete rest, a man of average size consumes about 0.25 liter of oxygen each minute to maintain body functions. Standing requires about twice this much, while light work requires three or four times this amount. A moderate work rate which can be maintained for quite a while by a man in good condition may require up to 2 liters of oxygen per minute. An oxygen consumption rate of 3 liters per minute represents exhausting work for an average man, but a man in excellent condition can consume as much as 4 liters per minute for a short time (10–15 minutes). A top-grade athlete might briefly maintain an oxygen consumption of 5 liters per minute.

(9) A diver's ability to work has a definite maximum limit because his heart and lungs have a maximum usage capacity, which limits the amount of oxygen he can deliver to his body cells. Anything which makes it harder for a man to breathe (1.3.5(24)) or decreases the effectiveness of his breathing (1.3.5(35)) will further limit his capacity for work. To permit a man to exceed his normal limits in an emergency, the body has the means of letting muscles work for a short time without adequate oxygen. This lack of adequate oxygen is called an oxygen debt. The extent to which this debt can be built is limited, and the required amount of oxygen has to be consumed later; but this ability can save a man's life. The better athlete a man is, the larger the oxygen debt he can build up and the harder he can work in an emergency.

(10) The *number of oxygen molecules* a diver consumes per minute is not influenced by his depth, although the *volume* of the oxygen concerned follows Boyle's law. A diver who is

TABLE 1–8.—*Oxygen consumption and respiratory minute volume at different work rates*

Activity [1]		Oxygen consumption [2] in liters/min [3] (STPD) [4]	Respiratory minute volume,[5] liters [3] (BTPS) [6]
REST	Bed rest (basal)	0.25	6
	Sitting quietly	.30	7
	Standing still	.40	9
LIGHT WORK	**Slow walking on hard bottom**	.6	13
	Walking, 2 mph	.7	16
	Swimming, 0.5 knot (slow)	.8	18
MODERATE WORK	**Slow walking on mud bottom**	1.1	23
	Walking, 4 mph	1.2	27
	Swimming, 0.85 knot (average speed)	1.4	30
	Maximum walking speed, hard bottom	1.5	34
HEAVY WORK	**Swimming, 1.0 knot**	1.8	40
	Maximum walking speed, mud bottom	1.8	40
SEVERE WORK	Running, 8 mph	2.0	50
	Swimming, 1.2 knots	2.5	60
	Uphill running	4.0	95

[1] Underwater activities are in boldface.

[2] All figures are average values. There is considerable variation between individuals. (See fig. 1–25 for range found in underwater swimming.)

[3] One liter equals approximately 1 quart.

[4] STPD means standard conditions (see 1.3.4(10)).

[5] The RMV values are approximate for the corresponding oxygen consumption. Individual variations are large.

[6] BTPS means body temperature, existing barometric pressure, saturated with water vapor at body temperature.

working hard enough to consume 2 liters of oxygen per minute at the surface would consume only 1 liter as measured at 33 feet; but the number of molecules he used would remain the same. If he were using a closed-circuit oxygen rebreathing apparatus (sec. 3.5), his oxygen consumption would, therefore, deplete the supply cylinder at the same rate regardless of his depth. To permit accurate comparisons, oxygen consumption should be expressed in terms of volumes as measured at the surface under *standard conditions* (zero degrees centigrade, 760 mm Hg barometric pressure, and dry gas). The abbreviation STPD indicates these conditions.

Carbon Dioxide Output

(11) The production of carbon dioxide closely follows the consumption of oxygen. For every liter of oxygen consumed, a man will normally produce close to a liter of carbon dioxide. As with oxygen consumption, the number of carbon dioxide molecules involved does not change with depth. The ratio between the amount of carbon dioxide produced and the amount of oxygen consumed is called the *respiratory quotient.* This can range from 0.7 to 1.0, depending on a man's diet and how hard he is working. The average value for a working diver is about 0.9. This means that nine-tenths of a liter of carbon dioxide is produced for every liter of oxygen consumed.

Volumes of Breathing

(12) The amount of air a man must move in and out of his lungs depends upon the amount of oxygen he must take in and the amount of carbon dioxide he must lose in order to maintain the normal levels of those gases in his body. Consequently, the volume of his breathing is closely related to his oxygen consumption and his carbon dioxide production. At the surface, the RMV is normally a little over 20 times the oxygen consumption. This ties in with the fact that expired air contains roughly 5 percent less oxygen and 5 percent more carbon dioxide than

inspired air. As shown in table 1-8, the RMV can range from about 6 liters during a period of rest to 100 or more liters during very severe exertion.

(13) Under normal conditions at the surface and, more particularly, under usual diving conditions where the partial pressure of oxygen is increased by compression of more molecules into the same volume of air, a man breathes mainly to eliminate excess carbon dioxide. If he succeeds in eliminating this excess, an ample supply of oxygen is generally assured. The actual *volume* of air required to eliminate carbon dioxide and keep the body's carbon dioxide tensions at a certain level does not change noticeably with depth. A man who is doing the same amount of work and holding the same arterial carbon dioxide tension will, therefore, have almost exactly the same RMV—in terms of volume as measured at his depth—regardless of the depth to which he goes. Because of the compression of gas, this means that the number of molecules of air (and the volume as measured at the surface) increases in proportion to the absolute pressure. This is why a demand apparatus cylinder which suffices for an hour at a certain work rate at the surface may last only 30 minutes at a depth of 33 feet or 15 minutes at a depth of 99 feet. If a man's actual lung ventilation does decrease at a depth, this means that he either has reduced his carbon dioxide production by slackening his work rate or has allowed his carbon dioxide tension to rise (1.3.5(13)).

Ventilation of the Lungs

(14) The relationships between carbon dioxide production and ventilation are important enough to deserve further consideration. They apply to numerous questions about breathing, breathing apparatus, and the ventilation of diving helmets.

(15) Actually, the body strives not so much to get rid of carbon dioxide as it strives to maintain the proper tension of that gas in the arterial blood and throughout the system. Losing too much carbon dioxide by overbreathing (*hyperventilation*) can upset the function of the body as badly as retaining an excess of that gas (1.3.5(45)). As has been previously explained, the normal tension of carbon dioxide in the arterial blood is about 40 mm Hg. Although arterial blood and alveolar gas are in equilibrium with each other as far as carbon dioxide is concerned, the arterial tension depends on the alveolar partial pressure of that gas; this pressure must, therefore, be kept at about 40 mm Hg. What 40 mm Hg represent in terms of percentage depends upon the absolute pressure, so the percentage of carbon dioxide in the alveoli must decrease with increasing depth.

NOTE

The effects of carbon dioxide depend upon the *partial pressure* of that gas. Therefore, for example, breathing 1 percent carbon dioxide at 132 feet (5 atm abs) will have the same effect on a diver as if he were breathing 5 percent carbon dioxide at the surface (1 atm abs). *This is true because the partial pressure of carbon dioxide is the same in both cases.* Since it is customary to think of carbon dioxide and its effects in terms of percentages at the surface, the term *surface equivalent percentage* is often used. In the foregoing example, you could say that the surface equivalent of 1 percent carbon dioxide at 132 feet is 5 percent carbon dioxide. Six percent would be the surface equivalent of 2 percent carbon dioxide at 66 feet (3 atm abs) or of 3 percent carbon dioxide at 33 feet (2 atm abs), and so on.

(16) At the surface, the total pressure is 1 atm or 760 mm Hg. The water-vapor tension at lung temperature is 47 mm Hg. This leaves 713 mm (760—47) Hg as the total dry *gas* pressure. Carbon dioxide must account for about 40/713, or 5.6 percent of the dry gas pressure; therefore, enough gas must be brought in by alveolar ventilation to make up the remaining 94.4 percent of the gas pressure and volume. If the body is producing 2 liters of carbon dioxide per minute (volume as measured at lung temperature) and delivering this amount to the alveoli, the total volume of gas brought into the alveoli each minute *must* be such that 2 liters equals 5.6 percent of it. Knowing this, it is easy to calculate what the total gas volume of alveolar ventilation must be. *One* percent of the volume would be 2 liters/5.6, or about 0.36 liter; and the total must be 100 times that, or 36 liters. Under these conditions, if breathing brings 36 liters of fresh air *into* the alveoli in a minute, oxygen consumption will remove about 2 liters

of oxygen, 2 liters of carbon dioxide will be added, and the *exhaled* volume of alveolar gas will also be about 36 liters. (Note that this figure does not represent the total lung ventilation. Dead space ventilation must be added. See example (*e*) in par. (20) of this article.)

(17) At depth, the *partial pressure* of carbon dioxide in the alveoli must still remain at about 40 mm Hg. At 4 atm (99 feet), the total pressure will be 3,040 (760×4) mm Hg. Again subtracting the water vapor tension of 47 mm Hg, the total *gas* pressure is 3,040−47=2,993 mm Hg. The alveolar percentage of carbon dioxide is now only 40/2993, or about 1.34 percent. If the diver's carbon dioxide output remains at 2 liters per minute (in terms of volume at the surface), the actual volume of carbon dioxide reaching his alveoli at 99 feet is 2÷4=0.5 liter. The volume of fresh air required (measured at the depth) is now 0.50/1.34×100=about 37 liters. Were it not for the water-vapor factor, the volume would have been exactly what it was at the surface—36 liters. The difference in volume is so small it can usually be ignored. The question of depth can thus almost always be neglected in the calculation of lung ventilation, provided that it is understood that the answer represents *volume as measured at the depth concerned.* (If only *rough* estimates are being made, the water-vapor tension and the difference between volumes measured at STPD and at lung temperature, etc., can also be neglected.)

Ventilation of a Helmet

(18) The amount of air needed to ventilate a helmet can be estimated in the same way as net alveolar ventilation, and the situation may be easier to visualize. The diver exhales carbon dioxide into the helmet at a certain rate, and the supply hose pours air in at a certain rate. The air and the carbon dioxide mix together and come out the exhaust valve. Once a steady situation has been reached, carbon dioxide coming out in the exhaust every minute equals the diver's carbon dioxide production. Since the air and carbon dioxide are mixed in the helmet, the percentage of carbon dioxide in the exhaust is the same as that in the helmet. If the diver is producing 2 liters of carbon dioxide per minute and we wish to keep the carbon dioxide concentration in the helmet at 1 percent, then we must use enough air so that 2 liters equal 1 percent of the total volume coming out the exhaust. The total in this example must therefore be 200 liters. Basically, the situation is the same as in alveolar ventilation. As in that case, the required volume (as measured at depth) is virtually the same regardless of depth. Observe that neither the volume of the suit and helmet nor the amount of air the diver is breathing need be considered, only the CO_2 production.

Ventilation Formula and Examples

(19) The arithmetic involved in the estimation of lung or helmet ventilation can be summed up in one simple formula:

$$V=\frac{C}{D-A}\times 100$$

where

V=Volume of ventilation, as measured at depth concerned

C=Carbon dioxide output, volume as measured at the surface

D=Desired percentage of carbon dioxide (in alveoli or helmet)

A=Percentage of carbon dioxide in gas used for ventilation

(*a*) Procedures:

1. All volumes must be expressed in the same units. For example, if carbon dioxide output is expressed in *liters per minute*, the volume of ventilation must also be in liters per minute.

2. *Percentage of carbon dioxide* must be expressed as the *surface equivalent* percentage (see par. 15 of this article).

3. The exact conditions of measurement of gas volumes are not specified (temperature, water vapor tension, etc.); but under ordinary conditions, the range of variation of these factors does not produce any serious errors in rough estimates.

4. Rearrangement of the formula permits solving for any one of the variables if the other two are known.

(20) Some of the questions which can be answered by using this formula are illustrated by the following examples:

(*a*) A diver in suit and helmet is doing moderate work and producing 1.2 liters of carbon dioxide per minute. How much CO_2-free air must be used to ventilate his helmet to keep the partial pressure of carbon dioxide from exceeding the equivalent of 1 percent at the surface?

Solution (apply the formula):

$$V=\frac{1.2\text{ liters}}{1-0}\times 100=120\text{ liters}$$
(about 4.2 cu ft) per minute

This amount is approximately the volume (4.5 cubic feet) normally allowed for in calculating the air supply for helmet diving. If the diver works harder without greater ventilation, the percentage of carbon dioxide in the helmet must obviously rise. For example, if this diver's carbon dioxide output were doubled, his equivalent helmet percentage would rise to 2 percent, etc. (The amount of increase in ventilation is shown in the next few examples.)

(*b*) How much air would be required to keep the equivalent percentage of CO_2 at 1 percent if the same diver were doing very hard work and producing 3 liters of carbon dioxide per minute?

Solution:

$$V=\frac{3}{1-0}\times 100=300\text{ liters}$$
(about 10.5 cu ft) per minute

(*c*) If the diver is producing 1.2 liters of carbon dioxide per minute and breathing the surface equivalent of 2 percent CO_2 from his helmet, what *net alveolar ventilation* will he require to keep his arterial CO_2 tension at 40 mm Hg?

Solution: First recall that 40 mm Hg is equal to 40/713 or 5.6 percent CO_2 in surface terms. Then apply the formula:

$$V=\frac{1.2\text{ liters}}{5.6-2}\times 100=\frac{1.2}{3.6}\times 100=33.4\text{ liters}$$
(about 1.2 cu ft) per minute

(*d*) What net alveolar ventilation would suffice if the same diver had access to CO_2-free air from a demand apparatus?

Solution:

$$V=\frac{1.2\text{ liters}}{5.6-0}\times 100=21.4\text{ liters}$$
(about 0.76 cu ft) per minute

The percentage of CO_2 in the inspired air makes a large difference in the volume of breathing required to maintain a normal carbon dioxide level in the body.

(*e*) What *respiratory minute volume* would this net alveolar ventilation require if the diver's total *dead space* (his own and that in the scuba) was 0.6 liter and his respiratory rate was 20 breaths per minute?

Solution: He must use $0.6\times 20=-12$ liters to ventilate his dead space each minute, and this volume must be added to the net alveolar ventilation. His respiratory minute volume is thus $21.4+12=33.4$ liters (about 1.2 cu ft).

(*f*) This same diver, working at the same rate with the same demand apparatus, tries to save air. He cuts his respiratory rate to 10 breaths per minute and reduces his net alveolar ventilation so much that his arterial CO_2 tension rises to 60 mm Hg (high enough to produce some symptoms of carbon dioxide intoxication). How much does he save by ventilating the dead space only half as often? How much air does he save altogether?

Solution: By ventilating the 0.6-liter total dead space only 10 times a minute, the diver uses $0.6\times 10=6$ liters per minute for this purpose. This is a saving of 6 liters over his previous rate of 20 breaths per minute. The CO_2 tension of 60 mm Hg is equivalent to about 8.4 percent of CO_2 in surface terms, neglecting the water-vapor tension. Apply the formula to find his approximate net alveolar ventilation.

$$V=\frac{1.2}{8.4-0}\times 100=14.3\text{ liters per minute}$$

Adding the dead-space ventilation of 6 liters, this gives him a respiratory minute volume of 20.3 liters, and the total saving is 13.1 liters. (Note that the saving of air is considerable but should never be practiced because over half of the saving is at the expense of having a potentially dangerous carbon dioxide level. In a demand apparatus with less dead space, the reduction of respiratory *rate* would have contributed even less to the saving.)

(21) Thinking about the examples above should clarify a number of points about the relationship between a diver's work rate, his

breathing, the amount of air required to ventilate his helmet, and the like. Note, for example, that a diver using a demand apparatus needs much less air than is required to ventilate a helmet. He draws only an amount equivalent to his respiratory minute volume from the cylinders, while it takes several times that amount to keep carbon dioxide adequately expelled from a helmet. Also, the helmet diver is always receiving at least a small amount of carbon dioxide in his inspired air, and this makes it necessary for him to breathe at least a little more. However, a large dead space in a self-contained apparatus will cancel out most of the gain as far as the diver's breathing is concerned. Saving air by controlled breathing involves the danger of excessive carbon dioxide levels in the body. In a closed-circuit or semiclosed apparatus where oxygen is rebreathed through a carbon dioxide absorbent, trying to cut down on the volume of breathing serves no purpose at all. It cannot change oxygen consumption or carbon dioxide production in the least and the constant mass-flow gas-injection rate is present and does not change during the dive. It can only lead to a rise in alveolar and arterial carbon dioxide tensions. The effect of absorption failure and CO_2 buildup on breathing in such a system is illustrated by example (*c*) in paragraph 20 of this article. If a diver's natural adjustments fail to increase his breathing when there is an increase in either his CO_2 production or the inspired CO_2 level, his body tensions of that gas must rise, and the results can sometimes be serious (1.3.5 (12)).

1.3.5 RESPIRATORY PROBLEMS IN DIVING

(1) Many of a diver's physiological problems come about because he is under water and exposed to the pressures of depth. However, some of the difficulties related to his respiratory processes can occur at any depth or even on dry land. What these conditions have in common is that the moving of oxygen to the tissue cells or the removing of carbon dioxide (or both) is prevented or hindered at some stage. Depth, or the fact of submergence, may modify these problems as the diver faces them, but the basic difficulties remain the same.

Hypoxia

(2) The term *hypoxia* is applied to any situation in which the tissue cells fail to receive or utilize enough oxygen to maintain their life and normal function. The many steps in the path of oxygen from the atmosphere to its metabolic use by a tissue cell have been mentioned (1.3.2(4)). Hypoxia can result from interference with any phase of the process; consequently there are many possible causes of hypoxia and many situations in which it can develop. However, only a few of these causes and situations are of much importance in diving.

(3) One of the most obvious causes of hypoxia is the lack of anything to breathe, as when a scuba diver loses his mask or mouthpiece and is exposed directly to the water, or when his air supply fails completely. In other situations there may be enough air to move in and out of the lungs, but not enough oxygen available in this air. This condition can develop if a man is shut in a closed space, in a burning building where oxygen is consumed by fire or displaced by smoke, in a closed compartment where the oxidation of fresh paint or deteriorating stores has used up the oxygen, and in many similar situations. The same sort of thing can happen in a poorly purged closed-circuit or rescue-breathing appliance which contains enough nitrogen to permit continued breathing but in which the oxygen is consumed without adequate replacement. A continuous-flow semiclosed-circuit apparatus will produce hypoxia for the same reason if the flow of oxygen-bearing gas mixture ceases or falls off appreciably. Situations of this sort are the most serious causes of hypoxia in diving.

(4) Hypoxia will stop the normal function of *any* tissue cell in the body and will eventually kill it, but the cells of brain tissue are by far the most susceptible to its effects. Unconsciousness and death can occur from brain hypoxia before the effects on other tissues become very conspicuous. Unconsciousness will develop almost at once in sudden severe hypoxia. However, if hypoxia is less severe or develops gradually, other symptoms of interference with brain function will appear. The higher functions are the first to be affected, just as they are in alcoholic intoxication. The ability to concentrate

and think clearly, to exert fine control of the muscles, and to perform delicate or skill-requiring tasks are decreased at an early stage. Confusion, faulty judgment, emotional instability, interference with gross muscle function, and difficulty in standing and walking will follow. The victim of hypoxia is usually unable to understand that he is in trouble or to be concerned about his condition. In fact, he may have the sensation of increasing well-being while drowsiness and weakness develop and unconsciousness finally occurs. In this respect, gradual hypoxia is very much like intoxication with alcohol.

(5) When hypoxia develops, pulse rate and blood pressure increase as the body tries to offset the hypoxia by pumping more blood; a slight increase in breathing may also occur. However, none of these reactions is sufficient to serve as a warning, and very few individuals are able to recognize the mental effects of hypoxia in time to take effective action. Blueness (cyanosis) of the lips, nailbeds, and skin develops when the hemoglobin in the blood is unable to absorb oxygen and regain its red color on going through the lungs. However, this blueness is of no value as a warning sign to a diver and is seldom a *reliable* indicator of hypoxia even for a trained observer on dry land. The truth of the matter is that there is *no* natural warning by which a man can be sure of detecting the onset of hypoxia. It is the subtle nature of hypoxia which makes it a particularly serious hazard in any situation where it can develop without other warnings. A diver who loses his air supply is in danger from hypoxia, but he knows he is in trouble and usually has time to do something about it. He is much more fortunate than the man who steps into an oxygen-depleted atmosphere or who gradually uses up the oxygen in a rebreathing rig which contains an excess of nitrogen.

(6) It is the *partial pressure* of oxygen that determines whether the amount of oxygen in a breathing medium is or is not adequate. For example, air contains about 21 percent oxygen, and thus provides an oxygen partial pressure of about 0.21 atm (0.21×1 atm$=$0.21 atm). This pressure is ample, but a drop to 0.16 atm (16 percent oxygen at the surface) will cause the onset of hypoxic symptoms. If the oxygen partial pressure goes as low as 0.12 atm (12 percent at surface), most individuals will become hypoxic to the point of being nearly helpless. Consciousness is usually lost at about 0.10 atm (10 percent at surface), and below this level, permanent brain damage and death are only a matter of time. If the total pressure is low, as at high altitude, 21 percent oxygen will not be adequate. In diving, a lower percentage will suffice as long as the depth pressure is sufficient to maintain an adequate partial pressure of oxygen. For example, 5 percent oxygen should be enough if the diver is at 100 feet (5 percent oxygen $\times$ 4 atm$=$0.20-atm partial pressure of oxygen); but ascent would rapidly render him hypoxic unless the oxygen percentage were increased.

(7) If a man suffering from severe hypoxia is not rescued promptly, the interference with brain function will produce not only unconsciousness but also failure of the centers which control breathing. The heart usually continues beating for a time beyond this point. If the victim is given fresh air before his breathing stops, he will usually regain consciousness shortly and will recover completely. If breathing has stopped but heart action continues, artificial respiration may succeed in getting enough oxygen to the brain to revive the respiratory center so that spontaneous breathing will resume in time. In such a case there may already be serious damage to the higher centers, but even in these cases almost complete recovery of normal function may eventually occur. If heart action has ceased, there is little hope of reviving the victim by the usual methods. However, it is very difficult to be certain that the heart has stopped completely, so efforts at resuscitation must be continued until the victim is pronounced dead by a medical officer. Occasionally a man whose heart has stopped can be restored to life if his heart's pumping action is accomplished by hand (*cardiac massage*). This operation should be attempted only by trained personnel; unless it can be done almost at once following the stoppage, the chances of revival are extremely small.

Carbon Dioxide Excess

(8) An excess of carbon dioxide in the tissues (the medical term is *hypercapnia*) can be caused by anything that interferes with any step in the normal process of carbon dioxide transport and elimination. It can thus have many different causes. In diving, carbon dioxide excess usually occurs either because of an abnormal amount of the gas in a diver's breathing medium, or because something prevents him from breathing enough to rid his body of the carbon dioxide it is producing. The effects of carbon dioxide in the body depend upon the tension (partial pressure) of the gas. If there is carbon dioxide in the inspired air, both the concentration (percentage) and the total pressure of the gas must be considered.

(9) The amount of carbon dioxide in fresh air is very small (only about 0.033 percent). The gas is produced by oxidation and can thus be found in much larger concentrations in the presence of a fire, in closed spaces under certain conditions, in engine exhaust, and the like. (In most of these situations, either a lack of oxygen or the presence of carbon monoxide is a more serious problem than is the presence of carbon dioxide.) The use of carbon dioxide fire extinguishers is a special situation in which carbon dioxide from an external source can be a problem. In most diving situations, the source of excess carbon dioxide is a man's own metabolic processes. To maintain the proper level of carbon dioxide in his body a man must breathe enough to dilute the carbon dioxide which is being produced and delivered to his lungs; and if breathing is to be effective, the air available for breathing can contain only a small amount of carbon dioxide. Inadequate ventilation of the helmet, failure of the carbon dioxide absorption system in a closed-circuit rig, and other such circumstances may lead to an excess of carbon dioxide in the inspired gas. The relationships between carbon dioxide output, lung ventilation, helmet ventilation, and the like have been discussed previously.

(10) An excess of carbon dioxide in the body causes several different reactions. The most important ones in diving are those which affect the *brain*. In carbon dioxide excess, as in hypoxia, all tissues are affected, but brain tissue is the most susceptible. In several ways, the effects on brain function are similar to those of hypoxia. Confusion, loss of the ability to think clearly, drowsiness, and such effects become more severe as the degree of excess increases. A man who breathes as much as 10 percent carbon dioxide will generally lose consciousness. At 15 percent and above, muscular spasms and rigidity occur. Permanent brain damage and death are much less likely than in the case of hypoxia. If a diver loses consciousness solely because of excess carbon dioxide in his breathing medium, he generally revives rapidly when given fresh air. He will usually be quite normal within 15 minutes, and the aftereffects rarely include anything more than such symptoms as headache, nausea, or dizziness.

(11) An increase in the tension of carbon dioxide in the body normally affects the *respiratory center* in the brain to produce an increase in breathing (mainly an increase in the tidal volume). This increase in breathing is the body's attempt to bring the carbon dioxide tension back to a normal level. If the condition is caused by carbon dioxide in the inspired gas, the increase in breathing will be roughly proportional to the concentration of carbon dioxide. At the surface, an inspired concentration of 2 percent carbon dioxide will generally produce a measurable increase in respiratory minute volume, but the change is seldom large enough to be noticed by the diver. With 5 percent carbon dioxide, the increase is almost always sufficient to produce an uncomfortable sensation of panting and shortness of breath. However, there are large differences among individuals in the way their breathing reacts to carbon dioxide; and the amount of work a diver is doing, his depth, and his breathing medium can also influence the extent to which his breathing will be altered by carbon dioxide. At what point a man will *become aware* of an increase in his breathing also varies with his character, the work he is doing, and other similar factors.

(12) Ordinarily, increased breathing is definite and uncomfortable enough to warn a diver before the concentration of carbon dioxide has a dangerous effect on the brain. Under certain conditions, however, the increase in breathing in

some individuals may not be great enough to serve as a warning; and if the carbon dioxide level continues to rise, it may reach the point of causing unconsciousness. None of the *other* effects of carbon dioxide is a reliable warning, so a subnormal respiratory reaction can make carbon dioxide excess as subtle a hazard as hypoxia. In addition, a diver who notices an increase in his breathing but fails to take effective action promptly may soon become unable to take any action.

(13) Another aspect of an insufficient respiratory response to carbon dioxide is the possibility that a man can, in effect, poison himself. This self-poisoning can occur if a man's breathing rate is too low to eliminate the carbon dioxide he is producing. This fact explains a number of underwater accidents in which divers have lost consciousness for no apparent reason. Deliberate reduction of breathing rate to conserve oxygen in the use of open-circuit scuba, although it is successfully practiced by many divers, is never a safe procedure. Breathing must not be restrained unless it is absolutely necessary to do so in an emergency. Conditions which seem to increase the likelihood of self-poisoning by carbon dioxide include unusual exertion, high partial pressures of oxygen, greater depths, and certain defects of breathing apparatus (such as excessive dead space and high breathing resistance).

Other Effects of Carbon Dioxide

(14) Abnormally high carbon dioxide tensions in the body not only alter brain function and breathing but also produce several other effects such as an increase in blood pressure and heart rate (pulse). If the exposure to carbon dioxide is ended abruptly, there sometimes is a brief drop in blood pressure sufficient to cause fainting. Carbon dioxide excess also dilates the arteries of the brain. This dilation may help explain the headaches often associated with carbon dioxide poisoning, but headaches are more likely to follow the exposure than to occur during it. It is believed that the great increase in bloodflow through the brain resulting from dilation of the arteries explains why carbon dioxide excess speeds the onset of oxygen poisoning (see 1.3.11(15)). *Excess carbon dioxide* breathed during a dive is also believed to increase the likelihood of decompression sickness, but the reasons for this increase are unclear. Unfortunately, such effects as changes in pulse and blood pressure are of no value as warnings to the diver. Such others as headache, unusual sweating, fatigue, or a general feeling of discomfort may warn a diver if they are recognized when and if they occur; but they are not very reliable warnings.

Asphyxia, Suffocation, and Strangulation

(15) The term *asphyxia* indicates the existence of *both* hypoxia and carbon dioxide excess in the body. Asphyxia will result if, for any reason, breathing ceases. Breathing an atmosphere that is both low in oxygen and high in carbon dioxide will also produce it. In many situations, carbon dioxide excess or hypoxia occur separately; therefore, the more specific terms should be used where possible. However, if hypoxia is severe or prolonged enough to stop a man's breathing, carbon dioxide excess will rapidly develop and the condition will then be true asphyxia. The term *suffocation* is sometimes used to indicate cessation of breathing from any cause, or to indicate the asphyxia that results.

(16) *Strangulation* indicates a choking or throttling stoppage of breath due to obstruction of a man's airway. This stoppage can be the result of such mishaps as a crushing injury to the windpipe; the lodging of an inhaled foreign object (such as gum or a false tooth) in the windpipe; a spasm of the larynx; a marked swelling of the lining of the air passages; the falling back of the tongue into the throat of an unconscious man; or the inhalation of water, saliva, or vomitus. A victim of strangulation will generally struggle violently and try to breathe in spite of the partial or total obstruction. This struggle may continue even after he has lost consciousness from asphyxia; however, when the asphyxia reaches a certain level, the attempt to breathe will cease. The possibility of strangulation must, therefore, be considered in any individual who is unconscious and not breathing. Artificial respiration will produce little or no movement of air in the presence of strangulation. Consequently, one of the very first steps in resuscitation must be a thorough examination of the windpipe for any possible

obstruction. Also, the possibility of strangulation is the main reason for keeping the victim in a face-down position, so that the tongue will fall forward and any fluids present will drain from the mouth. If it is evident that strangulation exists and that the victim cannot be relieved promptly by any other means, making an incision in the middle of the trachea (windpipe) below the larynx (voice box) may be the only way to save the man's life. This operation is called an *emergency tracheotomy* (see app. A).

Carbon Monoxide Poisoning

(17) *Circumstances.*—The presence of carbon monoxide (CO) (1.2.3(8)) in a diver's air supply is a serious potential danger. Possible sources, methods of analysis, safe limits, and methods of removal of carbon monoxide are discussed in appendix B (which covers carbon monoxide analysis and purity standards for compressed air).

(18) *Mechanism.*—Carbon monoxide produces its harmful effects by combining with the hemoglobin in red blood cells and rendering it incapable of carrying oxygen to the tissues. When this has happened, tissue hypoxia develops, even though the supply of oxygen to the lungs is ample and the arterial oxygen *tension* remains high. Hemoglobin combines with carbon monoxide about 200 times as readily as it does with oxygen. This is why even very small concentrations of CO can be very dangerous. In spite of the displacement of oxygen, hemoglobin combined with CO has a bright red color. As a result, a man who is hypoxic because of carbon monoxide poisoning does not show the cyanosis (blueness) often seen in other types of hypoxia. In fact, victims of CO poisoning can sometimes be easily recognized as such because of the unnatural redness of the lips, of the nail beds, and sometimes of the skin.

(19) *Symptoms.*—Because hypoxia is the basic result of carbon monoxide poisoning, the symptoms are almost identical to those of other types of hypoxia (1.3.5(4)). The greatest danger is that unconsciousness may occur without reliable warning signs. If the concentration of carbon monoxide is high enough to cause the rapid onset of poisoning, the victim may not even be aware of weakness, dizziness, or confusion before he succumbs. If the development of toxicity is more gradual, such symptoms as tightness across the forehead, headache and pounding at the temples, or nausea and vomiting may be noted in some cases. If these symptoms occur and are recognized as warnings, prompt action may save the man's life; but these symptoms are not dependable.

(20) As in the case of hypoxia due to low oxygen concentration in the breathing mixture, being at depth may tend to offset somewhat the effects of carbon monoxide poisoning. The greater partial pressure of oxygen in air breathed at depth will force more oxygen into simple solution in the blood and compensate somewhat for the loss of hemoglobin's ability to carry oxygen to the tissues. Also an increase in oxygen partial pressure will displace CO from hemoglobin, therefore making it possible for more oxygen to be carried by the hemoglobin. Conspicuous effects of carbon monoxide, therefore, might not appear in a diver until he tries to surface. This delayed effect adds to the treacherous nature of carbon monoxide poisoning and further emphasizes the importance of *prevention.*

(21) *Treatment.*—The first step in treating carbon monoxide poisoning is to get the victim into fresh air. If he is not breathing, artificial respiration must be started at once. If oxygen is available, it should be given as soon as possible. The administration of oxygen increases the amount of oxygen which reaches the tissues in spite of the inactivated hemoglobin, and it also greatly increases the rate at which the hemoglobin is freed of carbon monoxide and returned to its active state. If adequate ventilation of the lungs is maintained, breathing carbon-monoxide-free air will eliminate most of the carbon monoxide from the blood in a few hours. If oxygen is used, the majority of the hemoglobin will be reconverted in 30 to 90 minutes. Use of an oxygen-carbon dioxide mixture has been thought to speed the process even further, but its practical value is now considered questionable.

(22) All the safety considerations related to unconsciousness and resuscitation must be observed. These considerations include evaluating the possibility that another accident or injury

may have occurred in addition to carbon monoxide poisoning. Often, recompression will be warranted simply because air embolism and cerebral decompression sickness cannot be ruled out in an unconscious diver. There is no objection to recompression of a diver poisoned by carbon monoxide. As a matter of fact, administration of oxygen at a safe pressure in the recompression chamber has been shown to be of great value in carbon monoxide poisoning. The use of treatment table 5 of table 1–31 may prove effective for recompression; or, if the victim is slow to respond, the use of treatment table 6 may be elected. However, the defect of blood oxygen transport *does not* eliminate the possibility of oxygen poisoning. Therefore, the same limits of oxygen exposure as used in the treatment tables must be observed. At depths greater than 60 feet, the increased oxygen partial pressure of the air itself should be of considerable help in getting more oxygen to the tissues and hastening the elimination of carbon monoxide (see tables 1–30 and 1–31, treatment tables 1, 2, 3, 4, 5A, and 6A, pp. 173, 174).

(23) If a victim of carbon monoxide poisoning resumes breathing and regains consciousness after a reasonably short period of treatment, the chances of complete recovery are good. The outcome is not so favorable if he remains in a coma for an extended period. Coma may indicate that considerable brain damage has occurred.

Excessive Resistance to Breathing

(24) Breathing can limit the amount of work a man can do because there are limits to his ability to do the *work of breathing*. When a man exerts himself physically, his breathing must increase. If his work of breathing reaches its limits in the process, he also reaches the limit of his ability to do physical work. If a disease process either increases the work of breathing or decreases the ability to do that work, a man will find that his work capacity is also limited. For example, a patient with severe asthma may have to work so hard to breathe that he has strength only to lie in bed and struggle for each breath.

(25) Any breathing appliance is bound to increase, to some extent, the work of breathing. An appliance that has high *breathing resistance* may so greatly increase it that adequate breathing is difficult even during ordinary exertion and impossible during hard work. Such an apparatus would not only be unpleasant to use but also could endanger a man's life in a situation requiring exceptionally hard work. Breathing resistance is not a problem in helmet-type diving equipment, but it is an important consideration in all of the usual types of self-contained breathing circuits.

(26) In a man's own respiratory system and in breathing appliances used on dry land, much of the work of breathing consists of moving air through the various air passages. *Airway resistance* is a highly important factor in self-contained equipment. In demand-type units, the demand regulator itself may offer serious resistance if it is not well designed and properly maintained. The resistance from this source will become worse with increasing depth, because the compression of the air requires more and more molecules to pass through the small openings in the regulator with each breath. In any type of self-contained apparatus, restrictions in the breathing tubes, valves, or other components will cause resistance. Any abrupt changes in the diameter of the passages, any projections into the airstream, or any sharp changes in the direction of flow will add to the difficulty by producing *turbulent* flow. When turbulence is present, the density of the breathing medium becomes a very important factor in resistance. For this reason, the resistance of a badly designed system will increase markedly with increasing depth and increasing compression of the gas. The same sort of changes take place to some extent even in a man's own airways, so an increase in breathing resistance may be noticeable at greater depths even in a helmet, or in a dry recompression chamber without any breathing appliance.

(27) Being under water at any depth introduces another factor which influences breathing resistance. Every suit-and-helmet diver knows that he cannot expand his chest against the outside water pressure unless he keeps his suit somewhat inflated nearly to the waist. If he does not, he is in much the same condition as a man who tries to breathe through an overlong snorkel tube. In that case, the air in the lungs is at surface pressure and thus cannot balance the

pressure of the water outside the chest. Even at 2 or 3 feet of depth the unbalanced outside pressure is enough to prevent full expansion of the chest by the inspiratory muscles. The same difficulty arises if a man under water holds a demand valve or breathing bag over his head and tries to inhale from it. If such a procedure is carried to extremes, the unbalanced *hydrostatic* pressure not only prevents inhalation but also introduces the risk of *thoracic squeeze.*

(28) Unbalanced hydrostatic pressure is a source of considerable breathing resistance even in more usual underwater situations. It is difficult to place demand valves, exhaust valves, breathing bags, and the like, so that lung pressure and the external pressure on the chest are exactly balanced. The ideal position for these components apparently would be at the *suprasternal notch* (the notch at the top of the breastbone), but this location is seldom practical. If a man is swimming horizontally with a type of open-circuit scuba that places the demand valve at the back of his neck, the demand valve diaphragm is at least 6 inches higher than the optimal point. To get air on inspiration, the man must therefore develop in his respiratory tract a negative pressure equal to at least 6 inches of water to overcome the hydrostatic imbalance. This pressure is in addition to the negative pressure required to open the valve and overcome the airway resistance. About the same thing would be true if he were wearing the breathing bag of a closed-circuit rig on his back. However, a demand valve or breathing bag located *below* the optimum point would have the opposite effect; the diver would have to develop an extra amount of positive pressure in his lungs in order to exhale. Up to a certain point, the body can accommodate itself to such effects of unbalanced hydrostatic pressure without apparent ill effects or great discomfort.

(29) Even if the various types of breathing resistance do not add up to more *work of breathing* than a diver can do, he works less comfortably and less effectively than he would with a more ideal system. In addition, the respiratory muscles become fatigued just as other muscles do, and the amount of resistance they can overcome decreases with time. Therefore, a breathing unit that is usable for a short dive may not be satisfactory for a long one if much work is required. One of the most important things to realize is that the compression and increased density of air make the breathing resistance of almost any scuba increase considerably with depth. A unit that seems sufficient near the surface may prove to be almost unusable at depth. All these factors are carefully considered in the evaluation of equipment for Navy use, but even the best units available leave room for improvement.

(30) Except in an extreme emergency, a man is not likely to breathe against resistance high enough to seriously damage his lungs. Generally, soreness of the respiratory muscles is the only conspicuous aftereffect of a dive with gear having poor breathing characteristics. The limitation of the amount of work a man can do is usually the most serious aspect of excessive resistance. However, one additional factor should be mentioned. As the work of breathing increases, the body appears to reach a point at which it will accept a rising arterial carbon dioxide tension rather than perform the respiratory work required to maintain normal carbon dioxide tension. The point at which this acceptance occurs probably differs considerably among individuals. It is possible that in some individuals, an excess of breathing resistance could lead to some degree of carbon dioxide intoxication and its related problems. In any case, it makes good sense to use equipment with the lowest breathing resistance available, to maintain it in the best possible condition, and to try to remedy (or at least impede) the condition when breathing resistance seems unusually high.

Overexertion

(31) Almost everyone has had the experience of being out of breath from working too hard or running too fast. The respiratory response to exertion takes time to develop fully, so it is possible for a man to exceed his normal work capacity by quite a margin before he realizes that he has done so. Under normal conditions on land, this respiratory response is seldom a serious problem. Shortness of breath normally passes rapidly when work is slowed or stopped. In addition, most men learn their capacity for exertion. A runner expects to be short of breath

after a sprint, and he knows that he cannot use his top speed at the beginning of a mile race.

(32) Underwater, and especially at increased depths, the problem of overexertion is considerably more serious than it is on land. Because of the additional breathing resistance in self-contained apparatus (and in a man's own airways at greater depth), the work of breathing is increased and the capacity for physical exertion is diminished. An effort which would scarcely affect him on land may bring a diver to the point of real air hunger. If the breathing apparatus is especially poor, he may not be able to get sufficient air no matter how hard he works for it. The sensation of impending suffocation is far from pleasant, and it has led more than one inexperienced diver into panic and a serious accident.

(33) An experienced diver will generally have a good idea of his limits with the gear he is using. When he uses unfamiliar equipment, he will gradually increase his work rate so that he will not exceed his limits and will not suddenly be faced by severe shortness of breath. If he does find himself in that kind of distress, he is able to avoid panic because he knows the sensation will pass before long if he reduces or stops his work rate.

(34) Overexertion has aspects other than those concerned with breathing. There are definite limits to what a man's muscles can do, and it is not easy to judge how much strength one has in reserve. A diver who wastes energy or tires himself unnecessarily may find that it is difficult to complete his task. A man who neglects his physical condition may discover that what was once a normal work rate now tires him very quickly. Even a man in good athletic condition can expect to have sore muscles if he overdoes an activity to which he is not accustomed.

Excessive Dead Space

(35) The dead space of the respiratory tract has previously been defined. Any type of breathing apparatus will add to this dead space to a degree dependent upon its internal volume and arrangement of parts. The effect of added dead space in a breathing circuit can be understood by considering what would happen if a man breathed through a long tube having an internal volume of 1 liter. When the man exhaled, he would leave the tube filled with alveolar gas. He would then take this gas back into his lungs on the next inspiration, and he would not obtain fresh air unless he inhaled more than 1 liter. Therefore, in order to maintain normal ventilation of his lungs, he would have to increase his tidal volume by an amount equal to the volume of the added dead space. In this example, each breath would have to be 1 liter larger than would otherwise be needed. The tube would contain a liter of fresh air at the end of each inhalation, and this air would be expelled from the tube on the next expiration without ever having gotten to the lungs. Not only does the man have to do more work in the process of breathing, but he also must waste a considerable amount of air.

(36) In actual *breathing equipment*, dead spaces as large as a liter are not likely to be found; however, certain full-face masks, for example, can add one-half of a liter or more. If a man used such equipment and increased his breathing accordingly, the rate at which he used air would increase enough to make quite a difference in the duration of the supply. The necessary increase in tidal volume due to the dead space might seriously limit his ability to do hard work. On the other hand, failure to increase his breathing or compensate for the dead space would cut down his net alveolar ventilation and would allow his arterial carbon dioxide tension to rise. Actually, an increase in carbon dioxide tension will occur to some degree with any amount of added dead space. The effect of dead space is never likely to be compensated completely because the increase in breathing is itself due to an increase in carbon dioxide tension. The larger the dead space is, or the less responsive a man's respiratory center is to carbon dioxide, the higher the tension will be. Symptoms of CO_2 intoxication in some individuals may result from excessive added dead space under some conditions.

(37) In designing and evaluating breathing apparatus, it is naturally desirable to concentrate on having the least possible dead space. However, reducing it to the absolute minimum is not always possible because of other requirements. For example, a mouthpiece-type appa-

ratus generally adds less dead space than does one with a full-face mask; but if the unit is intended for use in a situation requiring voice communication and must be able to receive a microphone, then a mask must be used.

(38) The amount of exhaled air which a rig will return to a man's lungs on inhalation (the *effective* dead-space volume) cannot be determined merely by inspecting a circuit and measuring the volume of parts which appear to be dead. A well-designed mask may have considerably less effective dead space than the actual volume of space inside, and the dead space of a mouthpiece circuit sometimes proves unexpectedly large. In evaluation of equipment, effective dead space is measured with a machine that simulates a man's breathing and determines how much exhaled gas is actually rebreathed with inhalation.

Breath Holding

(39) Diving *without* breathing apparatus requires breath holding, and methods of prolonging the length of time the breath can be held are always of interest to skindivers and the like. The discomfort which forces a man to resume breathing arises largely from the two main mechanisms concerned with the control of breathing (1.3.4(6)). Rising carbon dioxide tension directly stimulates the respiratory center, while falling oxygen tension stimulates it via the chemoreceptors. As the degree of stimulation increases, it becomes more and more difficult to restrain the urge to breathe; and at some point, the individual will break and resume breathing.

(40) To some extent, experience and willpower influence the amount of respiratory stimulation a man can tolerate before breaking. In addition, individuals differ in the sensitivity of their control mechanisms, so one man will not have as strong a desire to breathe as another even though his oxygen and carbon dioxide tensions have reached the same level. Both of these factors help explain why one man may have a greater breath-holding ability than another. The improvement in breath-holding ability which occurs with practice is probably due mainly to increased willpower, but there is some evidence that sensitivity to the controls may be reduced over a long period of frequent skindiving.

(41) It is the combined effect of rising carbon dioxide tension and falling oxygen tension that produces the drive to resume breathing. Consequently, anything that slows the rate of change of either tension will increase the duration of breath holding. The breath can be held longer if the lungs are nearly full than if they are at the normal inspiratory or expiratory position. Presumably this is because full lungs provide a larger reservoir of oxygen and a larger space for carbon dioxide. Hyperventilation (overbreathing) prolongs breath holding because it initially lowers the carbon dioxide tension and thus lets more time elapse before this tension reaches the level of stimulation. Hyperventilation make very little difference in the oxygen tension. Breathing oxygen prior to breath holding leaves the lungs filled with oxygen, thus keeping the body's oxygen tension at or above the normal level for a considerable period. This procedure generally increases the breath-holding time even more than hyperventilation does. A diver at depth can hold his breath longer than he can at the surface, probably because of the increased number of oxygen molecules compressed into the air in his lungs. If oxygen breathing and hyperventilation are combined (hyperventilation with oxygen), the breath-holding time can be extremely long—over 10 minutes in some recorded cases.

(42) All these procedures for prolonging breath holding involve some degree of potential risk in skindiving. For example, hyperventilation lets the oxygen tension drop almost to the hypoxic level before the breakpoint is reached. If a man hyperventilates and then dives to a considerable depth, he will be able to hold his breath comfortably for quite a period of time. Not only has his tension been reduced, but also the partial pressure of oxygen in his lungs is maintained to some degree by the depth pressure. However, when the diver finally ascends, the partial pressure of oxygen in his lungs will drop sharply. He may experience a severe increase in the desire to breathe before he can reach the surface, and in some cases skindivers have lost consciousness from hypoxia during ascent under these conditions. Breathing oxygen before a breath-holding dive permits a man's carbon dioxide tension to reach a high

level before he is obliged to resume breathing. Under some conditions, the carbon dioxide tension may be high enough to have harmful effects. Hyperventilation with oxygen appears to be a particularly hazardous procedure for the prolongation of breath holding, especially if a man exercises while holding his breath.

(43) Hyperventilation with air before a skindive is almost standard procedure and is reasonably safe if it is not carried to an extreme. Hyperventilation should not be continued to the point of actual dizziness, and the diver should start to surface as soon as he notices a definite urge to resume breathing. Underwater breath-holding contests, attempts to set records for underwater swimming distance, and the like should be avoided. Disturbances of heart action have resulted from feats of this kind, and over-enthusiastic breath holding has even resulted in a number of fatal accidents.

(44) Every few years, someone discovers that providing a little rebreathing bag will permit the extension of diving time without an air supply. It is reasoned that rebreathing lung air with the bag permits relatively fresh air from the dead space (mask, mouth, and windpipe) to be washed down into the lungs and thus lengthens the time a skindiver can get along without surfacing for air. This theory is partly true, but the process is not as simple and safe as it sounds. Research has shown that letting a man rebreathe his own stale air (or even mixtures which contain *less* oxygen and *more* carbon dioxide!) will keep him fairly comfortable for a while even when his oxygen and carbon dioxide levels have already passed their normal breakpoints. A rebreathing device therefore increases both of the potential hazards of prolonged breath holding. While some individuals probably could use the device safely, a man whose respiratory control mechanisms were relatively insensitive (or who tended to be too involved with his underwater pursuits) might be placed in real danger. Adding any carbon dioxide absorbent to such a rig would guarantee the development of serious hypoxia unless the lungs were initially filled with oxygen.

Hyperventilation

(45) *Hyperventilation* is the term applied to breathing *more* than is necessary to keep the body's carbon dioxide tensions at the proper level. It has already been discussed in the preceding paragraphs in connection with breath holding. If carried to an extreme, hyperventilation can be as undesirable and dangerous as conditions involving interference with breathing. *Unintentional* hyperventilation is most often triggered by nervous tension and can be experienced by normal individuals in any stress situation. It is also brought on by hypoxia and is a common and serious problem for aviators. Divers using self-contained equipment for the first few times are likely to hyperventilate to some extent, largely because of anxiety. Hyperventilation has little effect on the body's oxygen levels, but it can reduce carbon dioxide tensions to the point of producing serious symptoms.

(46) Symptoms of abnormally *low carbon dioxide tension* (*hypocapnia*) can be produced by voluntary hyperventilation (taking a number of deep breaths over a short period of time, as in preparation for a breath-hold dive). Under these circumstances, one rarely develops any more symptoms than lightheadedness and a tingling sensation; but when a man hyperventilates over a long period without realizing that he is doing so, additional symptoms such as weakness, headache, numbness, faintness, and blurring of vision may appear. Often, a nervous sensation of suffocation starts the process and continues in spite of it. The anxiety caused by the symptoms may lead to a further increase in breathing, and a vicious circle can thus develop. Severe hypocapnia with muscular spasms, loss of consciousness, and shock may be the result. Clear-cut cases this severe are extremely rare in diving, but the possibility deserves being remembered. Milder instances are probably common.

(47) Unsuspected hyperventilation is considered responsible for many of the vague symptoms which lead otherwise healthy people to seek medical attention. Mild cases are probably brought on by many common anxieties. Simply explaining the process may be sufficient to interrupt it. In more severe cases, having the individual rebreathe his expired air from a rubber bag or paper sack for a short while (less than a minute at a time because of the possibility of hypoxia) may relieve the symptoms and permit him to stop hyperventilating.

Hypoglycemia

(48) A condition not due to respiratory difficulties but sometimes confused with them is *hypoglycemia* (an abnormally low blood sugar level). Sugar, actually dextrose (glucose), derived from food is the body's main fuel. It is carried to the tissues by the blood; and if the blood sugar level falls for some reason, the functions of the tissues will be disturbed. The brain is especially sensitive to lack of dextrose. The highly variable symptoms can sometimes closely resemble those of other conditions in which brain function is affected, including *carbon dioxide intoxication*, *hypoxia*, *carbon monoxide poisoning*, or even *oxygen poisoning* and *air embolism*. Some of the more common symptoms are unusual hunger, excessive sweating, numbness, chilliness, headache, trembling, dizziness, confusion, lack of coordination, anxiety, and fainting. In severe cases, loss of consciousness and convulsions may occur.

(49) There are several possible causes of hypoglycemia. Simply missing a meal will tend to reduce the blood sugar level, but the body normally can draw on its stored supplies to keep the level close to normal for a long time. A few individuals who are otherwise in good health will develop some degree of hypoglycemia if they do not eat at fairly frequent intervals. Severe exercise on an empty stomach will occasionally bring on the symptoms, even in a man who ordinarily has no abnormality in this respect. The body secretes *insulin* to promote the normal use and storage of glucose. People with diabetes do not secrete enough insulin and for this reason have an excess of glucose in their blood. They must take insulin by injection to avoid the symptoms of diabetes and to keep their blood sugar level stable. If they happen to take too much insulin, or if such a factor as unexpected hard work reduces the amount needed, serious hypoglycemia can develop rapidly. This condition is the main reason that diabetics are considered bad risks for diving.

(50) If hypoglycemia is present, giving sugar by mouth (or by vein, if the victim is unconscious) will promptly relieve the symptoms and prove the diagnosis. If a diving operation will require doing without food for an unusually long period, eating protein foods like meat beforehand will provide a longer and steadier supply of dextrose than will starches and sweets. The latter can actually cause trouble in some individuals by causing the body to secrete an excess of insulin. A diver who often experiences definite weakness (or any other of the symptoms mentioned) when he misses meals should have a medical examination to determine whether hypoglycemia is the cause and, if so, why he is particularly susceptible to it.

1.3.6 EFFECTS OF PRESSURE

(1) The purpose of the following sections is to apply the previously covered principles of physics and physiology to a study of the changes that take place in the body upon application and release of excess pressures. The effects of increased pressures on the body can be divided into primary and secondary phenomena; the former include the mechanical effects of pressure upon the body cells and spaces, the latter cover the physiological effects which are due to altered partial pressures of gases in the breathing medium.

Effects of Pressure Applied Equally to All Parts of the Body

(2) The body is capable of withstanding tremendous pressures without changing because of the pressure itself. As was explained in the section on physics (1.2.4(13)), this capability is demonstrated if air has free access to all surfaces of the body including the linings of its natural air spaces—lungs, airways, middle-ear spaces, and sinuses. In this case, pressure itself has no effect even on the blood pressure and circulation. If the *pressure difference* between the inside of an artery and the surrounding water is measured at depth, the difference will prove to be the same as it was at the surface even if the depth pressure is very high. The *absolute* pressure in the artery has simply risen with the surrounding pressure. One might wonder, for example, why the brain is not crushed by the collapse of its protective skull. This accident would be possible if the brain were enclosed in a skull containing air at atmospheric pressure. However, the solids, fluids, and coverings of the brain occupy the entire space of the skull and are subjected to the same compressive force as

are the scalp and skull bones. The entire body (with the exception of its air spaces) is completely made up of fluids and solids which are virtually incompressible and freely transmit pressure.

Effects of Unequal Application of Pressure

(3) If, for any reason, a rigid air space in the body (or one attached to its surface) is sealed off and is thus unable to equalize pressure during descent, damage (squeeze) can result. In such a situation, a pressure difference as small as one-sixteenth of an atmosphere (about 1 pound per square inch or 2 feet of sea water) can begin to alter the normal shape of tissues by causing congestion, swelling, and bleeding of the tissues. Such changes, if allowed to continue, may cause an actual destruction of tissues as well as pain and shock.

(4) Unequal application of pressure can also occur on ascent if any air-containing structure which equalized on descent fails to do so when the diver surfaces. This occurrence is actually quite rare, because most of the spaces usually will easily vent the expanding air on ascent even if they gave trouble during descent. The main danger spot is the lungs. If the diver should happen to hold his breath during ascent, he may shortly be in serious trouble with *air embolism* or one of the related accidents which will be described later.

Indirect Effects of Pressure

(5) The discussion of *partial pressures* explained that the partial pressure of each gas in a mixture increases when the total pressure is elevated, as by descent. The increase in the partial pressure of a gas can have two types of effect. For one, the amount of any gas dissolved in the blood and tissues depends upon its partial pressure. When its partial pressure increases, so does the amount of gas in solution. In the case of inert gases such as nitrogen and helium, the excess amount in solution may cause trouble on ascent by leaving the solution as bubbles. The second type of effect appears with gases (such as oxygen, nitrogen, and carbon dioxide) which not only go into solution but have specific actions on body tissue. These actions are in proportion to the partial pressure of the gas. Even if these actions on body tissue are not noticeable under ordinary conditions, they will increase (sometimes to the point of causing troubles like nitrogen narcosis and oxygen poisoning) when the partial pressure is sufficiently increased. Effects of this kind will be discussed after the more direct ones have been covered.

1.3.7 EFFECTS OF PRESSURE DURING DESCENT

The Ears, Sinuses, and Teeth

(1) The human body contains several natural air spaces which, because of their small entrance passageways, often cause trouble when excess pressures are applied to the body. The most important of these are the middle-ear spaces and the nasal accessory sinuses.

(2) The anatomy of the *ear* is diagrammatically shown in figure 1-26. The eardrum completely seals off the outer-ear canal from the

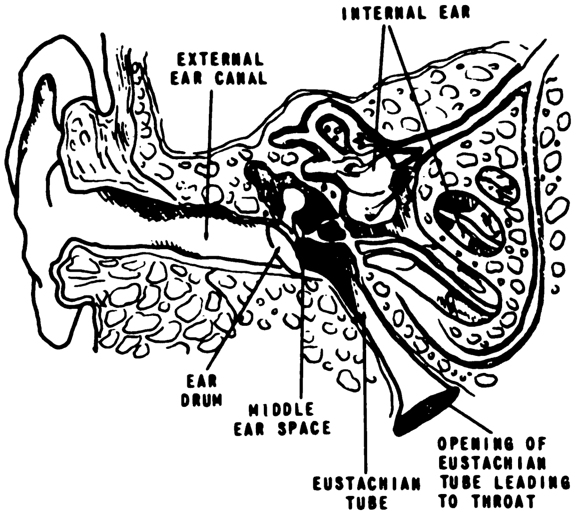

FIGURE 1-26.—Anatomy of the ear.

middle-ear space. When pressure is applied to the body, the outer surface of the eardrum is subjected to the same pressure as are all other surfaces of the body. To counterbalance this strain, air pressure must also reach the inner surface of the eardrum. This counterbalancing is accomplished by the passage of air through the narrow eustachian tube which leads from the throat to the middle-ear space. Should this tube be blocked by mucus or an overgrowth of tissue, the equalization of pressure on both sides of the eardrum cannot take place and severe pain will result. If the drum continues to be subjected to this one-sided pressure, it will bulge inward with such force as to tear blood vessels, cause hemorrhage, and finally rupture. Also, the lining of the middle-ear space itself is affected. Its blood vessels transmit the full external pressure, while the space with which they are in close contact remains at lower pressure. If this situation continues, the vessels will expand, start to hemorrhage, and finally burst. The pain produced before the drum ruptures often becomes so intense that it prevents further descent by the diver. Returning to normal pressures brings about immediate relief. Very often a slight blockage of the eustachian tube by mucus can be overcome by holding the nose and lips tightly and exerting inside pressure by forced expiration. Yawning, swallowing, and movement of the jaw may also be helpful in opening the eustachian tubes.

(3) The nasal accessory *sinuses* are shown diagrammatically in figure 1–27. All sinuses are located within hollow spaces in the skull bones and are lined with a mucus membrane continuous with that of the nasal cavity. Essentially the sinuses are small air pouches which connect with the nasal cavity through narrow passages. If pressure is applied to the body, and passages to any of the sinuses are obstructed by mucus or tissue growths, pain will soon be experienced in the obstructed area. The situation will be very much like that described for the middle ear. If normal air pressure is in the sinuses and an excess pressure is applied to the tissues surrounding these incompressible spaces, the same relative effect is produced as though a vacuum were created within these spaces. Swelling of the lining membranes and (if the pressure difference is high enough) hemorrhage into the sinus spaces will take place. This process represents an effort on the part of nature to balance the relative negative air pressure with swollen tissue, fluid, and blood. Squeeze on the sinuses actually takes place, and the pain produced may be severe enough to prevent further descent by the diver. Unless damage has already occurred, a return to normal pressures will bring about immediate relief of pain, as it does with pain from the middle ear. If such obstruction and pain has been encountered during a dive, the diver may often notice a small amount of blood on his handkerchief when he clears his nose on reaching the surface.

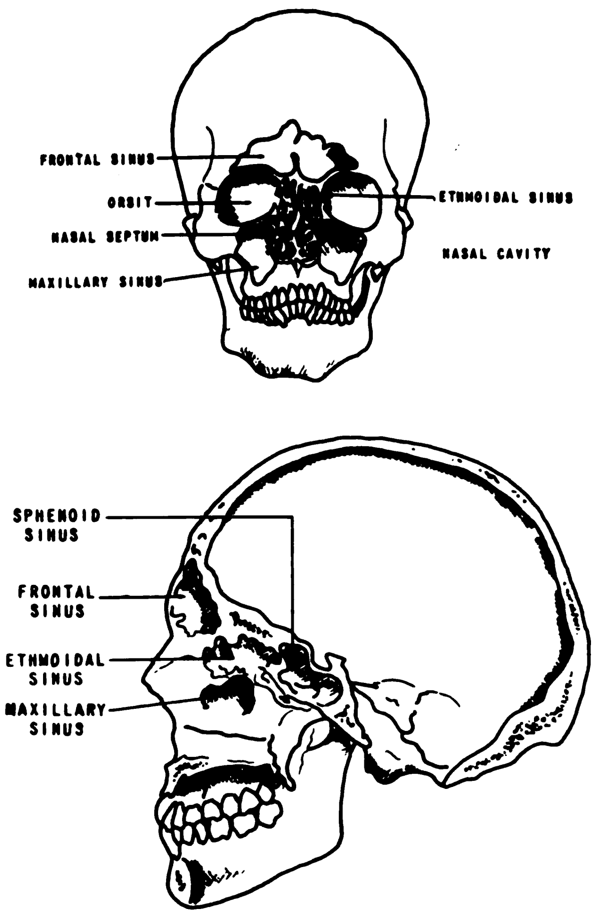

FIGURE 1–27.—Nasal accessory sinuses.

(4) If a *tooth* becomes painful during descent, this suggests the presence of a small gas pocket in the pulp or in a part of the tooth where soft tissues can experience squeeze. If a diver is wearing a tight-fitting hood or earplugs, he can develop an external-ear squeeze when the trapped air is compressed in the canal on descent. Tissue damage, hemorrhage, and finally an outward rupture of the eardrum will occur in an external-ear squeeze. This is the reason divers *do not* wear earplugs. When a hooded suit must be worn, air (or in some types, water) must be allowed to enter the hood to equalize pressure in the ear canal. Once in a great while, eardrum rupture occurs on ascent. This is probably caused by an obstruction of the eustachian tube after equalization has been ac-

complished on descent. Usually the tube vents air on ascent much more readily than it admits it during descent. When rupture of the eardrum occurs in a man who is diving with his ears exposed to *cold water*, the entry of cold water into the middle ear will violently upset his sense of balance. He will become extremely dizzy (true *vertigo* in this case), will usually become nauseated, and may vomit. While he is experiencing this reaction, he will probably lose all sense of position and direction. Fortunately, the reaction usually subsides in a minute or so as the water in the ear warms to body temperature.

Face or Body Squeeze

(5) Another type of squeeze encountered in diving is that produced when the air pressure within the face mask or helmet suddenly drops below the pressure of the surrounding water. This condition may occur in two ways: (1) when the air pressure within the supply lines suddenly drops either by failure of the supply or by bursting or parting of the air lines; and (2) when a sudden increase in the depth of the diver is not compensated for by an increased air supply. The physical mechanism of damage is the same as that in middle-ear or sinus squeeze, but the resulting injury is on a much larger scale. If such an accident occurs while a diver is using a face mask with rigid eyeglass mountings, the most likely tissues to be damaged are the membranes that cover the surface of the eyeball, that line the lids, and that line the spaces around the eyeball. There will be bleeding into these tissues, and bleeding can also occur in the socket behind the eyeball, forcing the eyes forward. If the accident occurs when a diver is using a deep-sea suit, his shoulders and body may be forcefully pushed into the helmet space with fatal results. It is because of these possibilities that a nonreturn valve in the supply line at the helmet or mask is *essential* in all surface-supplied diving procedures. Exposure suits, sometimes worn by shallow-water or self-contained divers, can also present a problem in equalization of pressure. Any dry-type suit will contain air spaces. Since the suit material has some substance to it, these spaces cannot flatten out completely; and a little air space is left between the suit material and the skin. During descent the skin may be squeezed into these spaces, causing discomfort and possibly some bleeding into the area. This condition is accompanied by external-ear squeeze if the suit is hooded. Admitting a little air to the suit will permit the spaces to equalize.

The Lungs—Thoracic Squeeze

(6) The effects of unequal air pressure on the lungs are demonstrated by the skindiver who makes a dive by merely holding his breath. Like any other diver, he is subjected to a compressive force of 1 atmosphere for every 33 feet of descent, but he has no source of air to compensate for this compression. At a depth of 100 feet, for example, the total pressure acting on his body amounts to about 4 atmospheres. At this depth, the amount of air which was present in his lungs at the surface (usually about 6 liters) is compressed to one-fourth its original volume, or 1½ liters. This amount approximates the residual volume of the lungs—the amount of air left in the lungs after the most forceful expiration. The depth to which the breath-holding diver can descend is therefore limited by the ratio of total lung capacity to residual volume. Should the diver descend further, the additional pressure will be unable to further compress the chest walls or elevate the diaphragm without causing injury. Injury will take the form of squeeze. Blood and tissue fluids will be forced into the lung alveoli and air passages where the residual air is under less pressure than the blood in the surrounding vessels. This hemorrhage amounts to an attempt by the body to relieve the negative pressure within the lungs by partially filling the air space with swollen tissue, fluid, and blood. Considerable lung damage, therefore, results. If the damage is severe enough, it may prove fatal. If the diver descends still further, death will result from the crushing of the chest walls, similar to the collapse of a sealed tin can when it is lowered into deep water.

Pressure and Increased Gas Density

(7) Another direct effect of pressure concerns the way *gas* behaves when it is *under pressure*. Breathing is more difficult at depth because the number of molecules in a given volume of gas is increased in direct proportion to the absolute

pressure, but the volume of each breath and the respiratory rate remain about the same. For example, air breathed at 100 feet of depth is approximately four times as dense (as heavy) as air at the surface. If open-circuit gear is being used at 100 feet, each breath involves moving four times as many molecules through the demand valve. In poorly designed or improvised equipment, the extra effort required for breathing at depth will prove to be quite noticeable and possibly limiting to the diver. Even moving air through the respiratory passages inside the body requires about twice as much effort at 100 feet as at the surface, and the maximum breathing capacity is reduced to approximately half. The extra work expended in the process of breathing alone reduces the overall ability to do heavy work at depth. The compression of gas also reduces the duration of the air supply of open-circuit scuba in direct proportion to the absolute pressure.

1.3.8 EFFECTS OF PRESSURE DURING ASCENT

Air Embolism

(1) *Traumatic air embolism* is a serious potential complication of diving caused by excess air pressure inside the lungs. It occurs most frequently in submarine escape procedures or in emergency ascents from dives made with scuba or the lightweight diving outfit. The conditions which produce this accident are directly opposite to those which produce lung squeeze. The immediate cause is holding the breath during ascent. For example, if an individual ascends to the surface from 100 feet, the air within his lungs will expand to four times its original volume. If this expanding air fills the lungs completely and is not allowed to escape, a pressure is built up within the lungs which is greater than the pressure surrounding the chest. This pressure overexpands the lung and ruptures its air sacs and blood vessels. Air is then forced into the pulmonary capillary bed, and air bubbles are carried to the left chambers of the heart. From there they are pumped into the arteries. Any bubble which is too large to go through an artery will lodge there and form an obstruction (embolus). The tissues beyond the embolus will then be deprived of their blood supply. The consequences depend upon the area or organ where the blockage occurs. The brain is frequently involved; and when it is, the symptoms are usually extremely serious. Unless the victim is recompressed promptly to reduce the size of the bubble and permit blood to flow again, death may follow. The symptoms and treatment of air embolism are discussed more fully in the section on diving hazards.

(2) If, as a test, one purposely holds his breath during ascent, a sensation of discomfort behind the breastbone and a feeling of actual stretching of the lungs will urge one to exhale at periodic intervals. A condition of fright, however, can apparently cause a spasm of the throat muscles which seals the main lung passageway and thus brings about overexpansion of the lungs. Under these circumstances, death has occurred in ascent from depths of only 15 feet. At least one case of air embolism has followed ascent from the bottom of a swimming pool. On the other hand, safe ascents can be made from depths of several hundred feet without any breathing appliance, provided the individual exhales continually during his ascent. Every diver should make it an absolute rule *always to breathe normally and continually during ascent.* If he is out of air or if his gear is not working and he cannot breathe, then he *must exhale as he ascends.*

Other Consequences of Excess Lung Pressure

(3) Ascent with failure to exhale can lead to three other conditions that may either accompany air embolism or occur separately:

(*a*) *Subcutaneous emphysema* refers to a swelling or inflation due to abnormal presence of air in the tissues. If emphysema is extreme, air embolism will usually be present also.

(*b*) *Mediastinal emphysema* is the result of air having been forced into the tissues about the heart, the major blood vessels, and the trachea (windpipe) in the middle of the chest. If the volume and pressure of this air are great enough, serious symptoms may result.

(*c*) *Pneumothorax* is the result of air having been forced into the potential space between the lung covering and the lining of the chest wall. An air pocket formed within the chest cavity, yet outside the surface of the lung, offers considerable difficulty if it occurs under increased pressure because there is no exit for the trapped air. As the pressure decreases during ascent to the surface, the volume of the trapped air increases; this increase collapses the lung on the affected side and pushes this collapsed lung and the heart toward the opposite side of chest. The collapse of the lung and shifting of the heart's position are serious developments because they interfere with both breathing and circulation.

Overexpansion of the Stomach and Intestine

(4) While a diver is under pressure, gas formation may take place within his intestines, or air may be swallowed and trapped in his stomach. During ascent this trapped gas expands and occasionally causes enough discomfort to the diver to require his stopping until it can be expelled. Continued ascent in spite of marked discomfort may result in actual harm. Chewing of gum during a dive can cause air to be swallowed and should therefore be avoided.

1.3.9 INDIRECT EFFECTS OF PRESSURE

(1) The conditions previously described are caused by *differences in pressure* which damage body structures in a direct, mechanical manner. The indirect or secondary effects of pressure are the result of changes in the partial pressures of individual gases in the diver's breathing medium. The mechanisms of these indirect effects include saturation and desaturation of body tissues with dissolved gas, and the modification of body functions by abnormal gas tensions. This section is concerned with the uptake of inert gases such as nitrogen and helium in a diver's body at depth; with the process of *decompression*, which aims to eliminate excess gas safely; and with the result of failure to accomplish this elimination (*decompression sickness*).

Nitrogen Absorption and Elimination

(2) When a person resides at sea level, his blood and all his tissues become saturated with dissolved nitrogen at a tension (partial pressure of dissolved gas) equal to the partial pressure of nitrogen in his lung alveoli—about 570 mm Hg (1.3.4(5)). If the person is then exposed to a breathing medium other than air or is taken to an altitude or depth, this change will alter the partial pressure of nitrogen in his alveoli. His blood and tissues must then either lose or take up nitrogen in order to reach equilibrium (state of balance) with the new alveolar nitrogen pressure (1.2.5(6)). The process of taking up more *nitrogen* is called *absorption*, saturation, or nitrogenation. The process of giving up *nitrogen* is correspondingly called *elimination*, desaturation, or denitrogenation. The chain of events is essentially the same in both of these processes, even though the direction of change is opposite. In diving, both processes are of interest: saturation, when the diver is exposed to an increased partial pressure of nitrogen at depth; desaturation, when he returns to the surface. (Basically, the same processes occur with helium and other inert gases as occur with nitrogen.)

(3) The sequence of events in the process of saturation can be illustrated by the changes which will occur in the body of a diver taken rapidly from the surface to a depth of 100 feet. To simplify matters, we can say that the tension of nitrogen in his blood and tissues on leaving the surface is roughly eight-tenths (0.8) of 1 atmosphere. When he reaches 100 feet, his alveolar nitrogen pressure will be about 0.8 of 4 atmospheres or 3.2 atmospheres, while his blood and tissues remain temporarily at 0.8 atmosphere. The partial-pressure difference or *gradient* between the alveolar air and the blood and tissues is thus $3.2-0.8=2.4$ atmospheres. This gradient is the force which makes molecules of nitrogen move (by diffusion) from one place to another. Consider the following events and factors in the diver at 100 feet:

(*a*) As blood passes through the alveolar capillaries, nitrogen molecules move from the alveolar air into the blood. By the time the blood leaves the lungs, it has reached equilibrium with the new alveolar nitrogen tension of about 3.2 atmospheres and contains about four times as much nitrogen as it did before.

(*b*) When this blood reaches the tissues, there is a similar gradient, and nitrogen molecules move from the blood into the tissues until equilibrium is reached.

(*c*) The volume of blood in a tissue is relatively small compared to the mass of tissue, and the blood can carry only a limited amount of nitrogen. Because of this fact, the volume of blood that reaches a tissue over a short period of time loses its excess nitrogen to the tissue without greatly increasing the tissue nitrogen tension.

(*d*) When the blood leaves the tissue, the venous blood nitrogen tension is equal to the new tissue nitrogen tension. When this blood goes through the lungs, it again reaches equilibrium at 3.2 atmospheres.

(*e*) When the blood returns to the tissue, it again loses nitrogen until a new equilibrium is reached.

(*f*) As the tissue nitrogen tension rises, the blood-tissue gradient decreases. Reaching equilibrium thus involves less loss of nitrogen from the blood and less gain of nitrogen in the tissues. The rate at which the tissue tension increases, therefore, becomes less rapid as the process proceeds. However, each volume of blood which reaches the tissue gives up some nitrogen and thus somewhat increases the tissue tension until complete saturation, in this case at 3.2 atmospheres of nitrogen, is reached.

(*g*) Tissues with a large blood supply in proportion to their mass have more nitrogen delivered to them in a certain amount of time and, therefore, approach complete saturation more rapidly than tissues that have a poor blood supply (fig. 1–28).

(*h*) If a tissue has an unusually large capacity for nitrogen, it will take longer for the blood to deliver enough nitrogen to saturate it completely. Nitrogen is about five times as soluble in fat as in water. Therefore, fatty tissues require much more nitrogen and much more time to saturate them completely than do watery tissues, even if the blood supply is ample. A fatty tissue with a poor blood supply saturates very slowly indeed.

(*i*) In the diver at 100 feet, the blood continues to take up more nitrogen in the lungs and to deliver more nitrogen to the tissues until all his tissues have reached saturation at 3.2 atmospheres of nitrogen tension. A few of his watery tissues which have an excellent blood supply will be almost completely saturated in a few minutes. Others (such as fatty tissues with a poor blood supply, or perhaps some watery tissues with an exceptionally meager blood supply) may not become completely saturated unless the diver remains at 100 feet for 24 hours or longer.

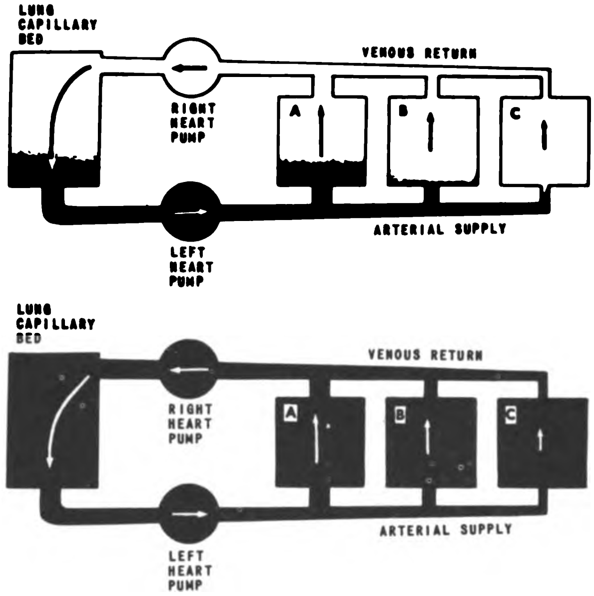

FIGURE 1–28.—Saturation of tissues. Shading in diagram indicates saturation with nitrogen or helium under increased pressure. Blood becomes saturated on passing through lungs, and tissues are saturated in turn via blood. Those with large supply (like A) are saturated much more rapidly than those with poor blood supply (like C) or an unusually large capacity for gas, as fatty tissues have for nitrogen. During a very abrupt ascent from depth, bubbles may form in arterial blood or in "fast" tissue (like A) even though body as a whole is far from saturation. If enough time elapses at depth, all tissues will become equally saturated, as shown in figure 1–29.

(*j*) If he remains at this depth of 100 feet until saturation is complete, the diver will contain about four times as much nitrogen in his body as he did at the surface. If he is of average size and weight, he contained about 1 liter of dissolved nitrogen at the surface and therefore will contain about 4 liters at 100 feet. Because fat holds approximately five times as much nitrogen as do watery tissues, much of the diver's nitrogen content will be in his fatty tissue, and an obese diver will contain considerably more nitrogen than a lean one.

(*k*) An important fact about nitrogen saturation is that the process requires the same length of time regardless of the nitrogen pressures involved. For example, if the diver had been taken to a depth of 33 feet instead of 100 feet, it would have taken equally as long to saturate him completely and to bring his nitrogen pressures to equilibrium. At this new depth, the gradient between alveolar air and the tissues would have been only 0.8 atmosphere instead of 2.4 atmospheres. Because of this gradient, the amount of nitrogen delivered to the tissues by each cycle of blood circulation would from the start have been smaller than it was at 100 feet. Less nitrogen would have to be delivered to saturate him at 33 feet, but the slower rate of delivery would cause the total time required to be the same as at 100 feet.

(4) The process of desaturation is the reverse of that which was described above, but the general concept is basically the same for both. Consider what would happen *if* the same diver were saturated at 100 feet and then *could* be brought immediately to the surface:

(*a*) The diver's blood and tissues contain dissolved nitrogen at a tension of 3.2 atmospheres when he leaves 100 feet. When he reaches the surface, his alveolar nitrogen pressure is back to the normal 0.8 atmosphere. There is now a gradient of 2.4 atmospheres tending to force the nitrogen out of solution.

(*b*) As the blood passes through the lungs, it loses nitrogen in order to reach equilibrium with the alveolar nitrogen pressure. When the blood returns to the tissues, it is thus able to take up nitrogen until it reaches the same nitrogen tension as that in the tissue.

(*c*) The amount of nitrogen each volume of blood can take up is limited, so the tissue nitrogen pressure cannot fall at once to the new level; however, each round of circulation transports some nitrogen from the tissue to the lungs, and the tissue tension gradually falls.

(*d*) The rate of blood flow and the amount of dissolved nitrogen in the tissues influence the rate of desaturation as they did of saturation. As in that process also, the rate of nitrogen transport decreases as the difference in tensions between the tissue and the incoming blood becomes smaller (as the gradient decreases) (fig. 1–29).

(*e*) Like saturation, complete desaturation to a new level may take 24 hours or more. Again, the length of time required is the same regardless of the original gradient. If the diver had

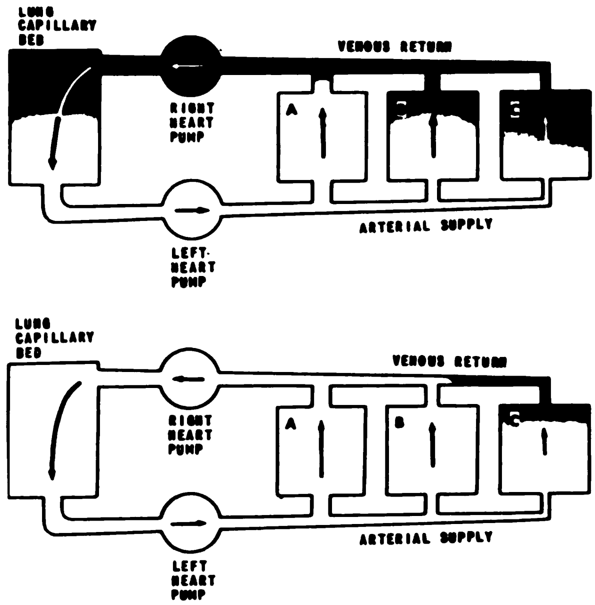

Figure 1–29.—Desaturation of tissues. The desaturation process is essentially the reverse of saturation. When pressure of inert gas is lowered, blood is cleared of excess gas as it goes through lungs. Blood then removes gas from tissues at rates dependent on amount of blood that flows through them each minute. Tissue with poor blood supply (as C in fig. 1–28) or large gas capacity will lag behind and may remain partially saturated after others have "cleared." (See lower diagram.) If dive is long enough to saturate such tissue, long decompression steps are required to desaturate it enough that bubbles will not form in it during ascent.

returned to the surface from 33 feet instead of 100, it would take equally as long for his tissues to return to equilibrium at 0.8 atmosphere of nitrogen pressure.

(5) Note that we said "*if* the diver *could* be brought immediately to the surface from 100 feet." The fact is that this *could not* be done without injuring him. If his tissues were saturated at 100 feet and thus contained dissolved nitrogen at a tension of 3.2 atmospheres, his returning to the surface would reduce the *total* pressure of the tissues to only 1 atmosphere. To have a dissolved-gas tension higher than the total pressure sounds like a physical impossibility. In a sense, it is. If a *tissue* is *supersaturated* with *gas* to this degree, the gas will come out of solution in the form of bubbles. This forming of bubbles results in *decompression sickness*, which will be discussed later on.

(6) Fortunately, the blood and tissues can hold gas in supersaturated solution to some degree without serious formation of bubbles. If this were not true, it would be impossible for a diver to ascend from any depth if any of his tissues had reached saturation during the dive. As it is, a diver can ascend at least part of the way regardless of the depth or the duration of his dive. This partial ascent creates an outward gradient for the dissolved gas, and the desaturation which occurs as a result of it permits the diver to ascend further after some period of time.

(7) By having the diver ascend initially as far as safely possible, stage decompression provides a considerable outward gradient for nitrogen. In actual practice, the diver then remains at his first decompression stop long enough to desaturate sufficiently to permit safe ascent to a stop 10 feet shallower. The process is continued until the diver can ascend all the way to the surface. When the diver reaches the surface, his body still contains nitrogen in supersaturated solution in some tissues; however, throughout the process of stage decompression the extent of supersaturation has been kept within limits that are normally safe. We have said that the processes both of saturation and of desaturation take the same length of time, but this statement is true only when the outward gradient is the same as the original inward gradient. If the stage decompression method is used, the outward gradient is necessarily kept smaller than the inward gradient by the stepwise ascent. However, since part of the desaturation can safely proceed at the surface, the total time of ascent is not always as prolonged as the slower rate of desaturation would indicate.

(8) During actual diving, a man is very seldom left at depth long enough for all his tissues to become completely saturated with nitrogen. In a very short dive, only those of his tissues which saturate rapidly will approach complete saturation, while those which saturate slowly may not take up enough gas even to approach dangerous supersaturation on ascent. Because the rapidly saturated tissues also lose nitrogen rapidly, they may desaturate considerably even during the ascent to the first stop. Within other limits, a few minutes at 10 feet provide enough decompression. Of course, this is not the case in longer, deeper dives.

(9) By making certain assumptions, it is possible to calculate the approximate degree of saturation existing in the body after any length of time at depth. Using Haldane's principle and information obtained by subsequent studies and experience, it is possible to compute the depths and durations of decompression stops which should permit the diver to ascend to the surface safely and efficiently. The *decompression tables* are based on such calculations, and have been checked by hundreds of test dives.

(10) *Standard decompression* is the procedure whereby a diver ascends to the surface with stops at various depths as described above, breathing the original gas mixture (usually air) throughout the ascent. This procedure is the form of decompression most frequently used, but other methods of decompression are possible. For example, it has been found that a diver can tolerate a serious degree of supersaturation in his tissues for a few minutes if he then is promptly placed under pressure. This makes it possible to use *surface decompression*, whereby the diver spends only part of his decompression time in the water and is then brought to the surface and rapidly placed in a recompression chamber for the completion of the process.

(11) Oxygen decompression takes advantage of another fact about desaturation and bubble formation: It is the gradient or partial pressure difference between the tissues and the alveolar air that causes denitrogenation of the tissues. It is the difference between tissue gas tension and the total external pressure on the body which is involved in bubble formation. If this distinction is understood, the principle of oxygen decompression should be clear. If the diver can breathe oxygen during his decompression stops, the nitrogen pressure in his alveoli is reduced nearly to zero. This reduction produces the largest possible outward gradient for nitrogen and brings nitrogen out of the tissues even more rapidly than would breathing air at the surface. At the same time, the total pressure on the body is maintained so that the formation of bubbles is no more likely than it would be if air were breathed at that stop. The result is a tremendous saving of decompression time. The use of

oxygen for decompression is possible only at depths where oxygen can be breathed safely (1.5.7(1)), and it is frequently not practical to supply a diver with oxygen. However, oxygen decompression is an integral part of helium-oxygen diving technique, and it is also used routinely in connection with surface decompression (1.5.5(5)). (It is sometimes suggested that substituting another gas, such as switching to helium-oxygen during decompression from an air dive, or vice versa, would accomplish the same thing as shifting to oxygen. It is true that this substitution would produce a high outward gradient for the original gas and that its elimination would be hastened. However, a high inward gradient would also be produced for the second gas. The resulting rapid uptake of this gas would tend to cancel the beneficial effect. It is evidently the *total* tension of dissolved gases in the tissues which determines bubble formation.)

(12) Although the foregoing discussion was concerned mainly with the *absorption* and *elimination* of nitrogen, the basic principles presented are also true for *helium.* However, there are differences between the two gases that cause the actual decompression procedures used for each gas to be quite dissimilar. Not all these differences and their consequences are as yet fully understood. One important difference between nitrogen and helium is the fact that helium, while it is about as soluble in water as nitrogen, is much less soluble in fat. Because fatty tissues thus have far less *capacity* for the absorption of helium, they will saturate and desaturate with that gas much more rapidly than they do with nitrogen. This rapid saturation and desaturation appears to give helium the advantage of requiring less decompression for long deep dives than is required when air is the breathing medium. However, the present helium-oxygen decompression tables actually require longer decompression for many depths and times than do the air decompression tables. It now appears probable that an increasing understanding of the behavior of helium in the body will permit a more favorable use of that gas from the standpoint of decompression. If this statement proves to be true, new tables will be computed, tested, and issued. Until that work can be accomplished, helium-oxygen mixtures will continue to be used because they provide freedom from nitrogen narcosis in deep dives, rather than because they offer much advantage in decompression.

(13) *High-oxygen mixtures*, those mixtures which contain a higher concentration of oxygen than that of air, can sometimes be *used as the breathing medium* to reduce the decompression time required by dives. As has been shown, the need for decompression stops on ascent stems from the fact that the body takes up inert gas in solution while the diver is at depth. It does so because of the increased partial pressure of the gas in the alveoli. The example of a diver breathing air at a depth of 100 feet was previously used, and it was pointed out that his blood and tissues tend to reach equilibrium with 3.2-atmosphere (approximate) partial pressure of nitrogen in his alveoli. If this diver breathed a 60-percent nitrogen–40-percent oxygen mixture instead of air at 100 feet, the nitrogen pressure in his alveoli would be about 2.4 atmospheres. This pressure is the nitrogen pressure normally present when air is breathed at a depth of 66 feet. If this nitrogen-oxygen mixture is used as the breathing medium, a 100-foot dive would, therefore, require only the much shorter decompression time of a 70-foot dive. The extent to which this principle can be applied is limited by the fact that it necessarily increases the partial pressure of oxygen, and exposure to oxygen must be kept within safe limits for both pressure and time. (These limits are discussed more fully in sec. 1.5 on breathing media and oxygen limits.) The helium-oxygen diving technique normally involves the use of mixtures containing as much oxygen as is considered safe for the particular dive in order to keep decompression time to the minimum. Therefore, the *mixture principle* is routinely applied in *helium-oxygen* and other mixed-gas diving.

(14) When its alveolar partial pressure is increased, *oxygen* will go into solution in the blood and tissues in added amounts in somewhat the same manner that nitrogen and helium do. However, the tissues are continually consuming oxygen, and consequently the tissue tension of that gas never can be as high as its

alveolar partial pressure. The amount of oxygen transported to the tissues seldom exceeds the needs of the tissues sufficiently to permit the development of a high degree of saturation. Also, when the external pressure decreases during ascent, the tissues are able to use up any excess oxygen fairly readily. The amount of oxygen present with other gases in the tissues may contribute to bubble formation when this decrease occurs, but only in extreme circumstances does the oxygen appear to be an important factor. *Pure oxygen*, if it could be used in deep diving, would probably be an ideal breathing medium from the standpoint of decompression. In reality, the limits of exposure that must be imposed because of the *danger* of *oxygen poisoning* restrict the use of oxygen to those depths and times which present no decompression problems even when air is the breathing medium.

Decompression Sickness

(15) When a diver's blood and tissues have absorbed nitrogen or helium in solution at depth, reduction of the external pressure on ascent can produce a state of supersaturation, as has been discussed. If the elimination of dissolved gas by the circulatory system and the lungs fails to keep up with the reduction of external pressure, the degree of supersaturation may reach the point at which the gas no longer can stay in solution.

(16) Liberation of bubbles can apparently take place either in the blood or in a supersaturated tissue. A bubble in the bloodstream would produce *symptoms* by blocking circulation. One in the tissue could put stretch or pressure on nerves or cause actual tissue damage. The symptoms which result depend on the location and size of the bubble or bubbles. These symptoms consist of pain in joints, muscles, or bones when a bubble is in one of these structures. Bubble formation in the brain can produce b'indness, dizziness, paralysis, or even unconsciousness and convulsions. When the spinal cord is affected, paralysis or loss of feeling in some part of the body can occur. Bubbles in the lungs can cause asphyxia or choking. Skin bubbles produce itching, rash, or both. Unusual fatigue or exhaustion after a dive is probably also due to bubbles, but the location of bubbles causing such symptoms is not known. Many other symptoms can be caused by bubbles in unusual locations. Decompression sickness which affects the central nervous system (brain or spinal cord) or lungs can produce serious disabilities and may even threaten life if not treated promptly and properly. When other areas such as joints are affected, the condition may produce excruciating pain and may lead to local damage if not treated, but life is seldom threatened.

(17) *Treatment* of decompression sickness is accomplished by recompression—putting the victim back under pressure to reduce the size of the bubbles and to cause them to go back into solution. This treatment is generally done in a *recompression chamber* but can sometimes be accomplished in the water if a chamber is not available. It must be done in a specified manner. Treatment in the water is *not recommended* and should be attempted only in an extreme emergency. The use of a nearby recompression chamber should always be considered first. Further discussion of the symptoms of decompression sickness and its treatment are presented in the section on diving hazards.

(18) *Prevention* of decompression sickness is generally accomplished by following the decompression tables correctly. Even when the tables are used correctly, however, unusual conditions either in the diver or in connection with the dive will produce a small percentage of decompression sickness cases. To be absolutely safe under all possible circumstances, the decompression time specified would have to be far in excess of that normally needed. On the other hand, under ideal circumstances, some individuals can ascend safely in less time than the tables specify. This fact must not be taken to mean that the tables contain an unnecessarily large safety factor. As a matter of fact, the tables generally represent the minimum decompression time that will permit average divers to surface safely from normal working dives without an unacceptable incidence of decompression sickness.

(19) Factors in the diver which apparently favor the development of decompression sickness even when the tables are correctly followed include age, obesity, excessive fatigue, loss of sleep, alcoholic indulgence and its aftereffects,

various illnesses, and anything which contributes to generally poor physical condition and poor circulatory efficiency. Unusually heavy exertion and extremes of temperature during the dive can have unfavorable effects. Heavy work at depths speeds up the circulation and increases the uptake of inert gas. Exercise during decompression, although it hastens the elimination of inert gas from some tissues, often increases the incidence of decompression sickness. Anything that impedes blood flow in an area during decompression can favor bubble formation. Keeping a leg or an arm in a cramped position is an example of a condition which would impede blood flow.

1.3.10 NITROGEN NARCOSIS

(1) Continuing the subject of *indirect effects of pressure* brings up the fact that the possibility of bubble formation during ascent is not the only undesirable result of exposure to increased partial pressures of nitrogen. When a diver breathes air at depth, the nitrogen produces an intoxicating effect similar to that of alcohol, anesthetic gases, or narcotic drugs. Some individuals are much more susceptible to this effect than others, but most divers are not aware of it until they reach approximately 100 feet of depth. Beyond 100 feet, the effect increases rapidly. Few divers can work very effectively at a depth much greater than 200 feet. Only very exceptional men are capable of doing useful work at a depth of 300 feet, and this depth is considered the limit for diving with air as the breathing medium.

(2) Nitrogen narcosis decreases the *ability to work* and causes changes in the mood of the diver. Just as different men are affected by alcohol to different degrees and in somewhat different ways, the response to nitrogen is not always the same; but a slowing of mental activity and a fixating of ideas are usually present. The diver finds it difficult to concentrate or to reason things out, and he may not be able to remember what he is supposed to do or even what he has already done. His reflexes and reaction times are slowed down. His observations will often be inaccurate, and he is likely to reach wrong conclusions about what to do.

(3) The greatest *hazard* of nitrogen narcosis is that it may keep the diver from caring about the job or even about his own safety. A stable and experienced diver will be reasonably productive and safe at depths where others fail. He is familiar with nitrogen narcosis, is keenly aware of the extent to which it impairs him, and makes a strong conscious effort to carry on in spite of it. He knows that he must be unusually careful, that he must spend more time and effort making even the simplest observations and decisions, and that any relaxation of his conscious effort can lead to failure or a fatal blunder.

(4) The exact *mechanism* by which nitrogen under pressure produces its narcotic effect is not known. The exact mechanism of action of anesthetic gases such as nitrous oxide (laughing gas) and cyclopropane is not known either, but the effects have much in common. It is probably correct to regard nitrogen as an anesthetic gas which happens to be so weak that it has no noticeable effect under normal conditions. When the dose (the partial pressure) is increased, the anesthetic effects of nitrogen increase progressively and become evident. The same relationship between pressure and effects is also true for other anesthetic gases. For example, nitrous oxide is not potent enough to produce complete surgical anesthesia by itself at the surface, but it becomes so when it is administered in a pressure chamber. The anesthetic potency of an inert gas (one which does not enter into actual chemical reactions in the body) is related to its solubility in oil (fat). If such a gas is exceptionally soluble in fat, it is generally a potent anesthetic. (The physiological concept which relates solubilities and anesthetic potency is known as the *Meyer-Overton theory.*)

(5) The fact that *helium* is relatively insoluble in fat has already been noted. The fact that it produces very little *narcotic effect* even at great diving depths makes helium very valuable for deep diving. If a diver breathes a helium-oxygen mixture, he can do useful work at a depth as great as 1,000 feet (and probably at even greater depths). The tremendous amount of decompression time required for such deep dives, even when the time at depth is only a few minutes, may tend to limit their practicability.

(6) Other inert gases, such as argon, krypton, and xenon, are not useful in diving because they have even greater narcotic effects than nitrogen. In fact, xenon is approximately equal to nitrous oxide as an anesthetic even at the surface. Except for hydrogen, which is difficult to use because of the danger of explosion, helium is the only gas known to be useful for deep diving.

1.3.11 OXYGEN POISONING

(1) The fact that oxygen is essential to life has been stressed throughout this chapter, and the specific effects of oxygen-lack hypoxia have been discussed in detail (1.3.5(2)). Although it may not seem reasonable that there could be such a thing as *too much* oxygen, this fact is an important one for a diver to realize.

Low-Pressure Oxygen Poisoning

(2) Even on dry land at normal pressure, it is possible for high concentrations of oxygen to have undesirable effects. For example, if more than 60 percent oxygen is breathed at the surface for a long enough period (many hours, or even days, are required), lung irritation may develop; and if the exposure is continued further, a form of pneumonia with actual lung damage may follow. This condition does not actually present much of a problem because such long exposures rarely happen except in hospitals, and the usual methods of giving oxygen (oxygen tents and the like) rarely give the patient as much as 60 percent oxygen. (More than this amount is seldom required for medical treatment.)

(3) Occasionally, a patient who has had a serious lung disability for a long time will lose consciousness when he is given oxygen. This reaction is due to the fact that he has been suffering from both hypoxia and carbon dioxide excess for so long that his respiratory center no longer responds to carbon dioxide, and he breathes only because of the stimulating effect of hypoxia on his chemoreceptors. Giving him oxygen satisfies his chemoreceptors, so they no longer impel him to breathe. The decrease in breathing which follows permits his carbon dioxide level to reach the point of causing unconsciousness. This condition is not oxygen poisoning in the true sense.

High-Pressure Oxygen Poisoning

(4) Divers do not usually have to worry about lung damage or blindness from breathing oxygen, but they can have other serious problems from it. The kind of oxygen poisoning that affects divers does not occur unless the partial pressure of oxygen is *above* that produced by breathing oxygen at the surface—somewhere above 1 atmosphere. When it occurs, high-pressure oxygen intoxication mainly affects the brain. If it goes far enough, it can cause convulsions (fits, seizures) very much like those of epilepsy. The convulsion itself rarely harms a man, but it can lead to a number of mishaps under water.

(5) The *minimum* partial pressure of oxygen that can cause this kind of trouble is not precisely known. High-pressure oxygen poisoning can definitely happen with an oxygen partial pressure of 2 atmospheres. (A man could expose himself to this partial pressure by breathing 100 percent oxygen at 33 feet, 50 percent oxygen at 99 feet, or air at approximately 280 feet.) A few cases of this type of oxygen poisoning have been reported at lesser pressures, and the time limits specified for oxygen exposure take this fact into account. The lower the oxygen partial pressure, the longer the time before symptoms develop. The safe periods at lower oxygen partial pressures are longer than most dives are likely to be.

(6) Because the partial pressure of oxygen (not the percentage) is the significant factor, a diver can encounter this problem not only when he is breathing pure oxygen, but also when he is breathing nitrogen-oxygen or helium-oxygen mixtures. Trouble is unlikely when air is breathed because of the required depths and the limits imposed by other factors such as nitrogen narcosis and decompression. Oxygen poisoning can be a problem in diving not only because oxygen and high-oxygen mixtures have to be used for some operations, but also because oxygen is used in decompression from helium-oxygen dives and in the treatment of decompression sickness. Operationally, high-oxygen partial pressures are most likely to be encountered in the use of closed- and semiclosed-circuit apparatus and with helium-oxygen equipment. In all these cases, the dive must be planned to

conform with the safe limits of exposure, oxygen percentage, depth, and time.

(7) Several factors besides the partial pressure influence the length of time before symptoms appear.

(*a*) *Exertion* is one of the most important factors. Most men at *complete rest in a dry chamber* can breathe pure oxygen for as long as 2 hours at 60 feet, and almost everybody can tolerate 30 minutes of oxygen breathing at rest at that depth. But if a man does light work, his safe time at 60 feet will drop to 10 or 15 minutes. For an average working dive, anything over 10 minutes at 40 feet is considered unduly hazardous.

(*b*) *Excess carbon dioxide* is another very important factor. Even a rather small amount of carbon dioxide in the inspired gas, less than the concentration likely to make the diver uncomfortable, can considerably shorten the latent period.

(*c*) There are also very great *individual differences* in susceptibility to oxygen poisoning. Some men can stand much greater exposure to oxygen than others, and an individual's tolerance also can vary quite a bit from day to day. The oxygen-tolerance test, which requires breathing pure oxygen for 30 minutes at 60 feet in a dry recompression chamber, is designed to detect those men who are unusually susceptible. The reasons for individual differences are not known.

(*d*) A number of other factors, such as temperature, also affect oxygen tolerance; but their influence is less clear cut than that of exercise and carbon dioxide.

Symptoms of Oxygen Poisoning

(8) Sometimes, early evidences of oxygen poisoning appear before convulsions. If recognized, these symptoms may give a man enough warning so that he can prevent further trouble by lowering the partial pressure of oxygen by ascent or other means. (He should also rest, and hyperventilating may aid him in averting more serious symptoms.) The warning symptoms most often noted, in approximate order of their likelihood of occurrence, are—

(*a*) *Muscular twitching.*—This usually appears first in the lips or elsewhere in the face, but it may affect any muscle.

(*b*) *Nausea.*—This may come and go periodically.

(*c*) *Dizziness.*

(*d*) *Abnormalties of vision or hearing.*—Tunnel vision—loss of the ability to see things to the sides—is one of the more frequent visual symptoms.

(*e*) *Difficulty in breathing.*—The diver may have air hunger, may sense an increase in breathing resistance for no apparent reason, or may have trouble taking a full breath into his lungs.

(*f*) *Anxiety and confusion.*

(*g*) *Unusual fatigue.*

(*h*) *Incoordination.*—Clumsiness, etc.

(9) Remember that these warnings do not always appear and may not be definite or early enough to be recognized in time for effective action. Note also that *some* of them can be caused by difficulties other than oxygen poisoning (including even the very opposite condition, hypoxia). However, if any one of the symptoms is definite, it usually represents a bodily signal of distress of some kind and deserves to be heeded. *Twitching* is the clearest warning of oxygen poisoning, but it may be a late one. If a man can breathe air for a while after the onset of symptoms, it will restore much of his tolerance and permit him to resume oxygen breathing. The exact period required to restore normal tolerance completely in man has not yet been determined.

(10) As has been indicated, *convulsions* are the most important consequence of poisoning due to excess oxygen. Convulsions can be caused by a number of things besides oxygen, such as various injuries to the brain and such diving accidents as air embolism and severe decompression sickness. In epilepsy, they occur spontaneously, usually without known cause. Fever will sometimes produce them in young children. Overdoses of certain drugs result in convulsions, and sometimes seizures are deliberately produced by drugs or electricity in the treatment of mental illness (shock therapy). During a convulsion, the individual loses consciousness, and his brain sends out uncontrolled and completely disorganized volleys of nerve impulses to his muscles. At the height of the seizure, all th muscles are being stimulated at once and

the body into boardlike stiffness. The brain soon fatigues, and the number of impulses drops off. In this phase, the random impulses to various muscles may cause violent thrashing and jerking of the body for a minute or so. Sometimes involuntary urination and defecation, and occasionally erection and ejaculation, take place during the convulsion. After the convulsive phase, the brain is completely tired out, and postconvulsive depression follows. During this phase, the patient is usually unconscious and quiet for a while, then becomes semiconscious and very restless. He will then usually sleep off and on, waking up occasionally but not being fully rational. The phase of depression sometimes lasts as little as 15 minutes, but an hour or more is not uncommon. At the end of it, the individual will often become alert rather suddenly and complain of no more than fatigue, muscular soreness, and possibly a headache. After an oxygen convulsion, the diver will usually remember clearly the events up to the moment when consciousness was lost, but will remember nothing of the convulsion itself and little of the depressed phase.

(11) Despite its rather alarming appearance, the convulsion itself is usually not much more than a strenuous muscular workout for the victim. In oxygen convulsions, even the possible danger of hypoxia during breath holding in the stiff phase is eliminated. The main dangers are from what may happen during the process of the convulsion. The tongue may be chewed when the jaw takes part in the jerking phase, and once in a great while a bone gives way under the strain of the contracting muscles. If convulsion occurs in a recompression chamber, one tender should be able to keep the man from thrashing against hard objects and hurting himself. Complete restraint of the movements is neither necessary nor desirable. Inserting a mouth bit (two or three tongue depressors wrapped in adhesive, or practically anything but a finger or a metal object) between the teeth during the chewing phase will avert damage to the victim's tongue. Breathing almost invariably resumes spontaneously, and turning the man on his stomach with his face to one side usually prevents respiratory obstruction. When the victim is wearing a suit and helmet, a convulsion might lead to blowup or squeeze, but bruises and chewed tongue are more likely to be the only consequences. Bringing a diver rapidly to the surface during the height of the convulsion could possibly lead to air embolism. If scuba is being used, the consequences of convulsions are likely to be more serious, with drowning the main danger. This is an example of a situation where use of the buddy system in self-contained diving can mean the difference between life and death (3.1.5(32)).

(12) Even if a man with oxygen poisoning continues to breathe oxygen, the convulsion will almost always cease in a few minutes and will be followed by a quiet interval of several minutes' duration. If the oxygen partial pressure is then lowered, there will seldom be a further seizure. Usually the convulsive phase is over before any drug can be injected to stop the seizure, and such treatment is necessary only in extremely rare cases where the convulsion continues after the oxygen pressure is lowered.

(13) If a man with oxygen convulsions is prevented from injuring himself or drowning, he can expect to recover promptly and have no lasting effects. Nor will he be any more or less susceptible to oxygen poisoning in the future. He may be more inclined to think he has warning symptoms during subsequent exposures to oxygen, but this inclination is most likely a psychological matter.

(14) The actual mechanism of oxygen poisoning remains unknown in spite of many theories and much research. At one time it was believed to be caused by the retention of carbon dioxide in the tissues. It is true that during exposure to high-oxygen pressures, there is so much dissolved oxygen in the blood that the tissues do not remove as much oxygen from the hemoglobin as usual. This process does keep hemoglobin from playing its full role in the transport of carbon dioxide from the tissues, but the resulting increase in actual tissue tensions of that gas is far less than that required to produce carbon dioxide convulsions (1.3.5 (10)). It is much more likely that oxygen has a direct effect of its own, possibly interfering with the enzyme systems of cell metabolism. The fact that carbon dioxide excess does speed the onset of convulsions is probably because

it increases blood flow to the brain and gives it a larger dose of oxygen. The influence of exercise remains unexplained.

Prevention

(15) From the diver's standpoint, *prevention* of oxygen poisoning is the most important thing. He should not use oxygen where there is no good reason for doing so. (For example, there is no reason to charge open-circuit gear with oxygen.) When the use of oxygen is advantageous or necessary, he should apply sensible precautions: being sure the breathing apparatus is in good order, *observing the depth-time limits*, avoiding excessive exertion, observing safety precautions, and heeding abnormal symptoms if they appear.

1.3.12 BREATHING MEDIA

(1) In view of the number of problems which arise because of the medium a diver *breathes*, a summarizing discussion of the various gases he *can* breathe may be useful.

Air

(2) Because it is the most available breathing medium, air is naturally the one most commonly used in diving. It is also the most satisfactory for most purposes. It has the disadvantage of requiring decompression in dives beyond certain depths and time. Nitrogen narcosis also limits the depth to which it can be used. In most surface-supplied diving, air is the most practical breathing medium to use. Special arrangements are generally required to make other gases practical with air-hose equipment. In self-contained diving, air can be used safely only with demand-type equipment; and the limited duration of the supply in this type equipment can be a serious drawback especially in deeper dives. The noise and bubbles of demand-type gear can also be a serious disadvantage in some diving operations.

Oxygen

(3) Except when employed in decompression procedures, oxygen is advantageous *only* when used with closed-circuit oxygen apparatus. The advantages include freedom from bubbles, almost completely silent operation, and maximum utilization of the gas. A small supply lasts a long time, and the duration of the supply is not altered by depth. The main disadvantage of oxygen is the limitations on depth and on time of use necessary to avoid oxygen poisoning. Oxygen does not normally produce decompression sickness, but at any rate decompression is not a problem within the depth-time range where oxygen can be used.

Nitrogen-Oxygen Mixtures

(4) Air is the most common nitrogen-oxygen mixture. It contains about 79 percent nitrogen and 21 percent oxygen. An artificial mixture with *less nitrogen* and *more oxygen* has the advantage of requiring less decompression time than air for a dive of the same depth and duration. Safe, efficient use of nitrogen-oxygen mixtures requires *special equipment*, usually semi-closed-circuit types. As in the use of oxygen itself, the possibility of oxygen poisoning restricts the safe depth and duration for use of high-oxygen mixtures. Nitrogen-oxygen does little to reduce the problem of nitrogen narcosis, because the oxygen limits are generally more restrictive than those imposed by narcosis. Use of nitrogen-oxygen mixtures requires careful selection of percentage, flow rate, and the like. The expected depth and duration of the dive, and the type of work to be done, must be considered carefully. A detailed description of the use of nitrogen-oxygen mixtures appears in section (3.6) on semiclosed-circuit scuba.

Helium-Oxygen Mixtures

(5) Avoidance of nitrogen narcosis in deep dives is the main purpose of using helium-oxygen mixtures. The present diving tables offer little or no advantage in the use of helium rather than nitrogen from the standpoint of decompression except in long, deep dives (1.3.9(12)). Helium-oxygen can be used in demand-type apparatus, but the limited duration of the supply at depth usually offsets the advantages. The fact that decompression from a helium-oxygen dive may be longer than the average, and that it requires a shift to oxygen on ascent, also adds complications. Helium-oxygen mixtures in semiclosed-circuit scuba diving have recently begun to be used for diving operations.

(6) As in nitrogen-oxygen mixtures, the percentage of oxygen in helium-oxygen mixtures must be kept within safe limits for the depth and duration of the dive to prevent oxygen poisoning. In dives deeper than approximately

300 feet, safety requires using less than 16 percent oxygen, unless exceptional exposures are required for operational reasons.

(7) Incidental effects of helium-oxygen mixtures include a striking change in the diver's voice (Donald Duck sound), more rapid loss of body heat in cold water (this situation requires special protective dress), and decreased airway resistance in breathing.

Hydrogen-Oxygen Mixtures

(8) Hydrogen may have roughly the same properties as helium as far as diving is concerned. The main complication in its use is the fact that hydrogen-oxygen mixtures are highly explosive unless the percentage of oxygen is kept very low.

Other Gases and Mixtures

(9) It has been pointed out in preceding paragraphs that any gas not actually used by the body is capable of producing decompression sickness (1.3.9) and that all the gases that have been investigated, except helium and hydrogen, are at least as narcotic under pressure as nitrogen (see 1.3.10(6)). It does not seem likely that any existing gas would be more satisfactory, from these standpoints, than those gases already in use.

(10) A procedure suggested for aiding decompression involves shifting from one inert gas to another during the course of a dive or the subsequent decompression (1.3.9(11)). Although switching to another gas will cause the first to come out of solution, the second gas will go *into* solution at a similar rate. It is not very likely that the procedure could reduce the final amount of dissolved gas to an important extent.

(11) The decompression advantage of increasing the oxygen content of the breathing medium (as in a high-oxygen mixture or in nitrogen-oxygen mixtures) has been mentioned. The possibility of oxygen poisoning limits the application of this principle rather severely. However, it has also been observed that exposure to near-normal oxygen partial pressure tends to restore a man's oxygen tolerance (1.3.11(10)). It is possible that providing breaks of proper duration would allow a diver to use a mixture of a much higher oxygen content than otherwise, and would thus greatly reduce his need for decompression. Determining such a procedure even to the point of safe tests would require a great amount of study and experimentation, but the eventual means of breaking through the depth-time barriers of diving may lie in some procedure such as this.

1.3.13 EFFECTS OF TEMPERATURE

(1) Extremes of temperature—most often *cold* water—can sometimes limit a diver's ability to stay submerged and do useful work more severely than any of the other physiological problems discussed so far. A man can live and function effectively only if the temperature of his body remains close to normal: 98.6° F (37° C). The body has an amazing ability to keep this aspect of its internal environment constant, but the natural adaptive mechanisms can function only so far in the face of extremes in the external surroundings. Beyond a certain point, protection has to be provided; and if this protection is not effective enough, several unfavorable consequences can follow.

Regulation of Body Temperature

(2) The body produces heat all the time, and it must continually lose an amount of heat equal to that produced (and no more) to keep its temperature constant. The amount of heat produced depends mainly upon the degree of exertion and is proportional to the oxygen consumption. A man at complete rest produces enough heat every hour to warm approximately 2 liters of ice-cold water to body temperature. If he is doing very heavy work he could warm nearly 23 liters (about 6 gallons) of ice water to body temperature in the same time. If a man doing moderate work could lose no heat at all, his body temperature would rise to 110° F in less than an hour; such a temperature would probably cause his death.

(3) Under ordinary conditions on dry land, the *body* has no trouble losing heat. If the surrounding air is cooler than the body, heat will be lost by conduction, convection, and radiation. In addition, some moisture is always evaporating from the skin, and this evaporation helps cool the body. If the rate of heat loss needs a boost, the control system will cause sweating, and the evaporation of the extra moisture cools the skin further. Evaporation cooling permits

heat loss even if the surrounding air is warmer than the body, as long as the air is not so humid that sweat cannot evaporate rapidly enough. The faster air moves over the body surface, the more rapid cooling will be, especially if the air is cool and dry. When the air is both hot and damp, the body may produce more heat than it can lose, and this can seriously limit the amount of work a man can do.

(4) In a normal range of temperatures, the body can control the rate of *heat loss* rather readily. In the warmer part of the range, this control is exerted mainly by increasing or decreasing the flow of sweat to produce more or less evaporation cooling. At lower temperatures, the rate of loss depends mainly on the difference between skin temperature and air temperature, and the control system can vary the skin temperature by varying the blood flow to the skin. This variation in blood flow is done via the nerves that control the muscle layers of the small arteries in the skin (1.3.3(3)). The cooler the skin, the smaller the heat loss.

Heat Loss Under Water

(5) Submerging the *body* causes several changes in temperature regulation. Cooling by evaporation is no longer possible, and conduction becomes the main method of losing heat. Water conducts heat away from the body so much more rapidly than air that a man can chill in water at a temperature which would be uncomfortably warm in moist air. Warming water requires about 3,000 times as much heat as warming the same volume of air to the same degree. In addition, an unclad diver's body is constantly bathed by unwarmed water, especially if he is moving about; so heat loss can be very rapid if the water is much cooler than the body.

(6) Because sweating and evaporation can no longer provide additional cooling, being submerged in water at or above body temperature will prevent any heat loss. If a man is working hard and producing much heat, temperatures above 86° F (30° C) can cause eventual overheating. Such temperatures are not often a problem in diving, but water this warm is found in some parts of the world, and it is much more difficult to protect the body against excessive heat than against cold.

Tolerance to Cold Water

(7) A diver is much more likely to encounter cold water than water that is too warm. The amount of cold he can tolerate without protection depends mainly on the amount of work he is doing. If he is producing a great deal of heat, it will take longer for his body temperature to fall to an uncomfortable level. There are also differences among individuals in their capacity to tolerate cold. An obese man has more bodily insulation and therefore can generally conserve body heat better than can a lean man. The body has a considerable amount of heat stored in it, and it does not lose heat all at once; so in a certain range of temperatures, an unprotected man can tolerate cold water if he does not have to remain in it too long. Figure 1–30 gives some information about approximate times at various temperatures and at what levels protection becomes necessary.

Effects of Cold

(8) When the surroundings are too cold, the body concentrates on keeping its most vital parts as warm as possible. To maintain this warmth, it will let the temperature of the skin and extremities fall, reducing the rate of heat loss to the minimum. When a man is comfortable, his average *skin* temperature is about 93° F (34° C). If his skin temperature falls below 88° F (31° C), he begins to feel uncomfortably cold. At approximately 86° F (30° C), the control system causes him to start *shivering*. Because shivering involves muscular work, it is a means of increasing heat production to slow the drop in temperature. If the temperature continues to fall, discomfort shortly becomes extreme. The hands (and to a lesser extent the feet) tolerate cold better than the body surface as a whole, but letting the skin temperature of the hands fall below about 60° F (15° C) will produce intolerable pain.

(9) Chilling, even if not severe enough to threaten life or cause permanent harm, produces more serious effects than mere discomfort and shivering. Loss of dexterity and of the sense of touch in the hands can make it very difficult for a diver to do useful work or even control his gear. Shivering causes a general lack of coordination, and may even make it difficult for a

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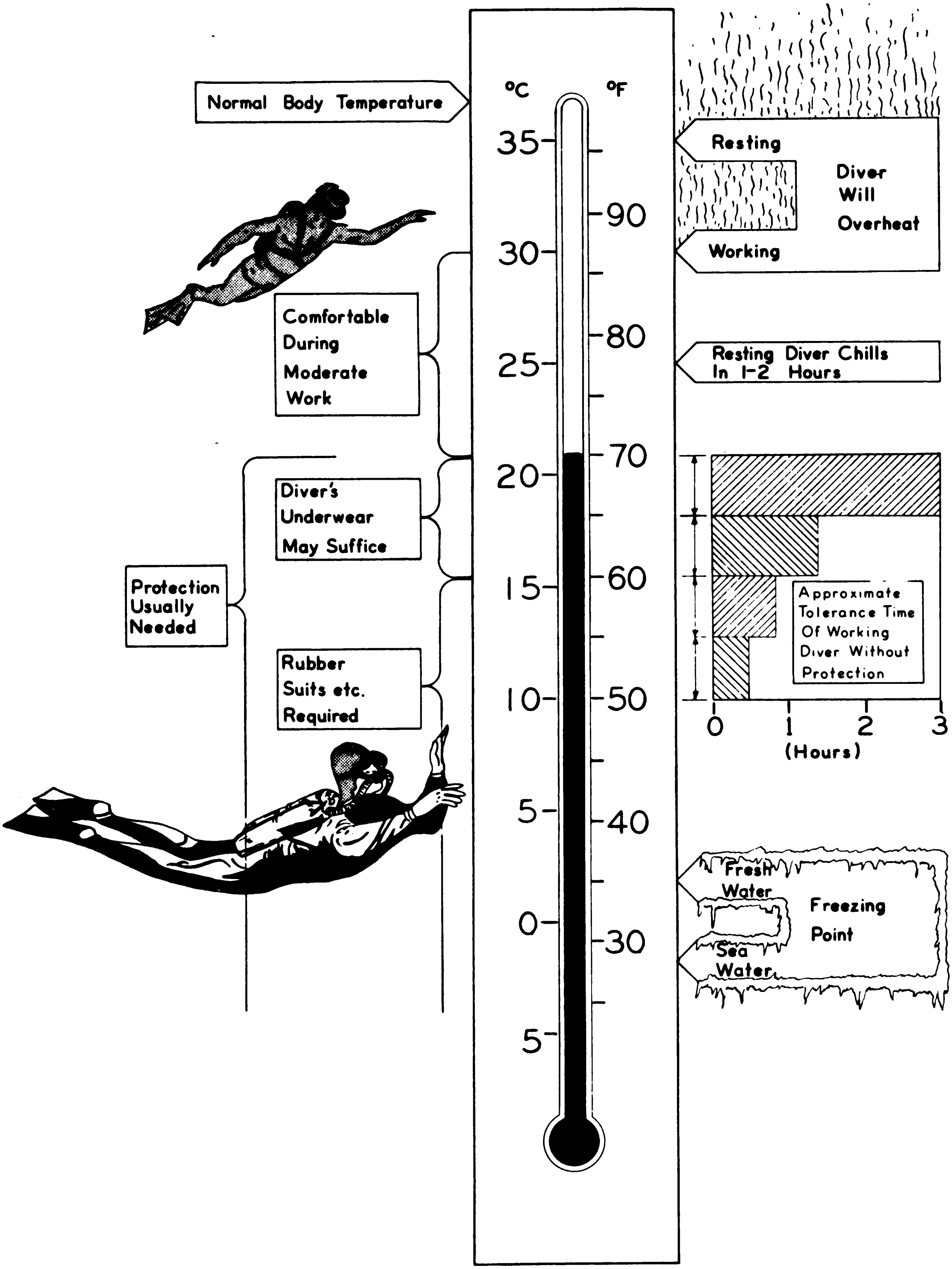

FIGURE 1–30.—Effects of water temperature.

scuba diver to maintain possession of his mouthpiece. A man's ability to think clearly may also be seriously affected by cold. All these effects can definitely increase the risks involved in a dive.

(10) Actual freezing of the hands or feet is not very probable even in icy sea water, nor is a diver likely to be in cold water long enough for long-exposure cold injuries like "immersion foot" to develop. However, a milder form of local injury (*chilblains*) is possible, especially if the exposure is long and the body as a whole is chilled in the process. (In this condition, subsequent warming causes the affected part to become swollen, red, hot, and tender; and itching may be severe.) The ability of an unprotected man to survive in extremely cold water is limited. At about 40° F (5° C), some men will die within an hour.

(11) In some situations, personnel at the surface are more likely to suffer from cold exposure than the diver, and the diver may be more likely to chill after surfacing than when he is submerged. Such circumstances are beyond the scope of this discussion, but they should be kept in mind. Adequate cold-weather and foul-weather gear must always be provided.

Cold-Water Protection

(12) A diver in deep-sea dress can usually wear enough underwear to keep himself warm for a reasonable period in cold water. Keeping his hands warm enough to retain touch and dexterity is likely to be his main problem. A scuba diver has more difficulty with cold. He generally prefers to wear no more than swim trunks, but figure 1–30 shows that the range of temperatures at which this outfit can be worn is very limited. If the water is not too cold or if the dive is short, the wearing of woolen underwear may be sufficient to protect the diver. This apparel merely cuts down on the amount of cold water which circulates next to his skin.

(13) Colder water requires actual *insulation* (1.2.9(16)). Wearing a rubber suit over bare skin is of little more value than wearing wet woolen underwear, because effective insulation requires placing a layer of air between the body and the water. Such a layer is provided by woolen underwear or other cloth materials which trap air in their interspaces. To be effective, these materials must be worn under a watertight rubber suit, and leaks or excessive sweating will destroy the insulating value. Unicellular plastic materials have gas trapped in small bubbles in the body of the material. These gas bubbles are effective insulators, and because the bubbles do not communicate with each other or with the outside surface of the material, the surfaces can become wet without losing their insulating properties.

(14) Because insulation requires the presence of air in some form, a self-contained diver who is sufficiently protected against very cold water may have trouble with buoyancy as well as with bulk and clumsiness. Compression of the trapped air with increasing depth will decrease both buoyancy and insulation. With a closed dry suit, it is generally possible to equalize the internal pressure to prevent suit squeeze, and doing so will also offset the loss of insulation. It is not possible to compensate for these effects when unicellular underwear is worn under a dry suit.

(15) It has previously been mentioned that helium conducts heat much more readily than does air. This fact means that a helium diver in suit and helmet derives much less protection from woolen underwear than he otherwise would. This lessened protection led to the development of electrically heated underwear for helium diving. Completely satisfactory protection of scuba divers who must work in arctic waters requires some similar means of providing additional heat. A number of heating principles might be employed.

Warming a Chilled Diver

(16) A diver who surfaces from a cold dive needs to regain body heat as rapidly as possible. If it can be provided, a hot shower is one of the best methods of rewarming. The man should at least change promptly into warm, dry clothes if at all possible. A few minutes of vigorous exercise will help stop any continued shivering. Hot, nourishing fluids like soup are also useful. The traditional shot of brandy, if available, will give a feeling of warmth by opening up the skin arteries and increasing blood flow. However, this action will only speed the loss of body heat if the surroundings are still cold;

therefore it is better to withhold spirits until rewarming by another method is underway.

Effects of Overheating

(17) Excessively high temperatures are not common in diving, but in some climates and waters they may affect both divers and surface personnel. It is necessary to insure an ample intake of fluids under hot conditions, and additional salt is also needed. Work should be kept to the practical minimum.

(18) Mild degrees of overheating can cause dizziness, headache, restlessness, difficulty in breathing, and fast pulse. If the condition is not relieved, it can proceed to *heat exhaustion* (heat prostration). In this condition, the victim becomes faint and weak, and then collapses. He will continue perspiring, and usually the skin is cold and clammy in spite of elevated body temperature. Usually, letting the victim rest in a cooler place and giving him a weak salt solution to drink (if he is still conscious) will bring about recovery, but medical assistance should be obtained if he fails to respond promptly. If a man suffers excessive salt loss from sweating, muscular twitching and cramps may occur.

(19) *Heat stroke* is an extremely serious consequence of overheating. Collapse is usually sudden, and the body temperature rises sharply. *The skin is dry and very hot*, and the pulse is extremely fast. *This is an acute emergency.* Unless the body temperature is lowered promptly by vigorous measures and unless other medical treatment is provided, death or permanent brain damage can result (see app. A).

1.3.14 UNDERWATER EXPLOSIONS

(1) The possibility of *exposure* to underwater blasts exists in several applications of diving. In cases such as demolition of underwater obstacles, the use of explosives is usually under the control of the personnel concerned. If such an operation is properly carried out, the risk of hazardous exposure is small. This circumstance is not always the case in work with underwater explosive ordnance. It is certainly not the case in operations where, for example, the enemy may use underwater explosives as a deterrent to the offensive operations of self-contained divers.

Factors Determining Degree of Injury

(2) Severe injury and death can result from the effects of blast following a nearby air or underwater explosion. The factors that determine the degree of injury sustained by affected personnel are—

(*a*) Proximity of the explosion.

(*b*) Size and character of the explosive.

(*c*) Medium through which the force is transmitted.

(*d*) Degree of submersion of the diver.

(*e*) Protection afforded the diver.

(*f*) Modifying factors, such as the character of the bottom in shallow water.

(3) *Proximity and size of the explosive* are considered together, because the approximate total force exerted by a blast wave on a diver can be calculated from a formula which involves both. The pressure exerted at a given distance by an underwater explosion of tetryl or TNT is expressed by the formula:

$$P = \frac{13{,}000\sqrt[3]{W}}{d}$$

where

P=force in pounds per square inch

W=weight of explosive in pounds

d=distance of explosion from diver (feet)

$\sqrt[3]{\ }$=cube root of

A sample calculation shows that a 600-pound charge at a distance of 50 feet exerts a pressure of 2,180 pounds per square inch. A pressure of 500 psi is sufficient to cause injury to the lungs and intestinal tract; therefore, one over 2,000 psi would certainly be fatal.

(4) An explosion produces a *shock wave* which travels through air or water in all directions, somewhat like the spread of ripples produced by dropping a stone into a pool. The initial compression wave (high-pressure peak) is produced by the violent liberation and expansion of gas during the detonation. A low-pressure wave (less pronounced) follows as a result of the subsequent collapse of the mass of expanded gas. The compression wave is the most destructive factor.

Mechanism of Injury

(5) If pressure of an underwater compression wave is above 500 psi when it reaches the surface of the water, the surface at that point

will literally be torn to shreds and blown up as fingerlike projections of water. This shredding effect helps explain the mechanism of blast damage to the body. In many ways, the damage is like a very abrupt and forceful local *squeeze*. The solid parts of the body are not damaged because they are largely composed of water and are incompressible. The pressure wave is simply transmitted through them without any disturbance, in the same way that the pressure of depth is transmitted. But when the pressure wave arrives at one of the body's air spaces, the situation is different. Even if the space has nonrigid walls (like an air pocket in the gut), the air does not compress and equalize the pressure at the same rate that the surrounding incompressible parts transmit it. This situation lets a large difference of pressure develop, exactly as it does when the compression wave hits the free air at the surface of the water. In the body, it is mainly the tissues which form the walls of the space (or tissues nearby) which tend to be shredded.

(6) The lungs and intestines are the most vulnerable areas. Because the head also contains air spaces, damage to these spaces and to the central nervous system can also occur if the diver's head is under water.

Influence of Various Factors

(7) The character of the explosive is an important factor in blast damage not only because different explosives vary in their total force, but also because the rate of explosion influences the nature and transmission of the pressure wave. An explosive that detonates very rapidly will produce a compression wave which has high pressure but very brief duration. If the detonation is less abrupt, the maximum pressure is lower but is sustained longer, and the wave does more damage at longer range under water. The transmitting medium is important because the incompressible nature of water lets it transmit the blast pressure with more force than air can transmit.

(8) The degree of injury is influenced by the diver's degree of submergence simply because parts of the body that are out of water are unaffected by an underwater blast. Being under water will provide a diver with protection in case of an air blast. Sometimes the depth of the water and the type of bottom influence the degree of injury. In some situations, reflections of the pressure wave from a hard bottom can apparently add to the damage.

Protective Measures

(9) *Protective clothing* made of materials such as foam rubber and kapok offers some protection against the effects of underwater blast. However, the bulk and buoyancy of the amount of material required for significant protection are considerable and rather impractical in diving. Use of rigid material in conjunction with a foam substance may increase the effectiveness of protection.

(10) If a diver expects an underwater explosion and has time to take any action, he should attempt to reach the surface and get as much of his body out of the water as possible, taking advantage of anything that he can climb up on or use for flotation. If he must remain in the water, he should float or swim face up to put the thicker tissues of his back between the vulnerable organs and the explosion. It is useless to cover the mouth or rectum because the mechanism of injury does *not* involve air or water being forced through these openings. If there is time, the diver should obviously get as far away as possible from the expected location of the explosion. If an air or surface blast is expected, the diver should remain submerged and, if he can, should go deeper.

Management of Casualties

(11) A man who is exposed to an underwater blast of any severity should receive medical attention whether or not he appears to be seriously injured. One reason for this procedure is that even a seemingly minor intestinal injury will sometimes produce a delayed perforation of the bowel. Such a development requires prompt surgical *treatment*.

1.3.15 NUCLEAR RADIATION

(1) The effects of nuclear weapons include blast, heat, and prompt radiation flux of the explosion itself, as well as delayed effects due to fallout and contamination. Of these *effects*, *contamination* resulting from bomb detonation is apt to be of most concern in diving. Beach landings of underwater demolition personnel and use of advanced land bases for diving operations

could involve risks due either to previous explosions and fallout or to deliberate spreading of radioactive fission products by the enemy.

(2) Land contaminated by radioactive material is likely to present a great hazard to personnel. In a surface or underwater burst, contamination from bomb debris and the presence of some induced radioactivity are the main factors. Water tends to become less radioactive than land because of dispersion, dilution, and precipitation. The bottom may become dangerously contaminated. The necessity of working on ships and other structures exposed to nuclear explosion can present special problems for *divers.*

(3) When diving operations are undertaken in a radioactive area, a preliminary survey should be made. Land, water, the bottom, and any other possible area of contamination should be investigated. If a radiation hazard of any degree exists, personnel should be equipped with dosimeters and all appropriate limits and precautions should be observed.

(4) The use of radioactive isotopes for various purposes is likely to become more frequent in diving, as it has in industry. Proper handling of such materials and ample safeguards are of vital importance and should conform to recognized radiological safety precautions.

SECTION 1.4 BASIC DIVING PROCEDURE

1.4.1 ORGANIZATION AND PLANNING

Command Responsibility

(1) The *responsibility* of the commanding officer is clearly defined in the U.S. Navy Regulations. He may at his discretion delegate authority to his subordinates for the execution of details; such delegation of authority shall in no way relieve him of his continued responsibility for the safety, well-being, and efficiency of his entire command.

(2) An officer must be assigned the responsibility for any and all diving performed by the command. He is known as the *diving officer*. In the absence of a qualified diving officer, any officer may be assigned. Such an officer must study all diving publications currently in use, and must make certain that all safety regulations are observed and that all diving is conducted in accordance with good diving practice. Prior to the commencement of combined diving operations, the Officer in Charge of the U.S. Navy divers shall, if circumstances permit, request a conference regarding diving safety. An enlisted *diver* whose competency, responsibility, and reliability are commensurate with the particular operation may be designated as the *diving supervisor*. The term "diving supervisor" as used in the manual denotes that person, officer or enlisted, who has been delegated the authority to take charge of a particular diving operation. One person, the diving supervisor, must be in complete charge at the scene. No diving operation may be commenced without a diving supervisor. To fulfill his responsibility and maintain proper *standards*, a good diving officer confers with the diving supervisor at those times that do not interfere with the proper conduct of the operation. Under no circumstance does the diving officer tolerate violations of outlined procedures. This manual is in a looseleaf binding for the benefit of the man with a better method than these outlined procedures. Instructions in the Special Note at the front of this manual give the procedure to follow in recommending an improvement (see app. F).

Planning and Foresight

(3) Diving, as much as *any other* military operation, needs *planning* and foresight. Bottom time is at a premium. The diver must be placed on the job under the optimum conditions of knowledge, equipment, ability, safety, and freedom from distractions. Topside assistance must be well organized and capable. Failure to consider any item of available information during the planning stage may result in failure of the diving operation. Time spent by the supervisor in determining conditions under which the diver will work will inevitably result in greater efficiency once the job is commenced. Circumstances such as changing weather conditions often prohibit a second attempt to complete diving operations that failed because the supervisor did not initially select the proper equipment, personnel, or procedure. Most important, the lives of many divers have been jeopardized by lack of foresight and failure to consider all eventualities.

(4) With the necessary amount of individual emphasis demanded by the size of the job, analyze and plan the job as outlined below. If any phase produces information that should have been considered in a previous step, reconsider the original analysis and replan that step.

(*a*) *Objective.*—Decide exactly what it is that must be accomplished. Review the objective carefully to insure that it is feasible and necessary.

(*b*) *Procedure.*—First and foremost, establish that the objective cannot be realized more simply by surface seamanship and rigging. Then outline a general plan. Consider all phases up to completion and securing.

(*c*) *Peculiar hazards.*—All diving is essentially hazardous. Protection against normal hazards is the reason for the establishment of minimum personnel qualification requirements, standardized procedures, and equipment specifications. The fact that the diving supervisor is qualified to conduct the type of operation at hand presupposes that he will combat normal hazards with standard procedures. At the same time, almost every diving operation will have conditions that are particularly hazardous or that might easily generate a hazardous condition. Review the entire outlined procedure and include all special precautions necessary to combat such conditions.

(*d*) *Surface conditions.*—Surface conditions include weather, sea, and topside equipment and personnel. Equipment (and personnel) includes that outside the command as well as that within the command. The important surface conditions to consider are either those available for use if required, or those that constitute a potential hazard to the diving operations. In the planning phase, take into account all present and expected surface conditions.

(*e*) *Underwater conditions.* — Underwater conditions include the worksite, the depth, the tide, the underwater current and visibility, and the type of bottom. Make certain that every one of these conditions is used to your advantage.

(*f*) *The dive.*—The dive includes more than the simple process of descent, work, and ascent by the diver. The organization and the ability of personnel topside are, in the final analysis, as critical as the individual ability of the diver himself. Most military diving operations require much preparatory and supporting effort. The most common failing of diving supervisors is to overplan the dive itself while underplanning all of the preparatory and supporting work. Plan the dive properly. Select your diving and supporting equipment. Outline your intended plan to your entire crew. Include plans for emergencies and any additional special items. Properly organize and train your surface crew to do their assigned jobs in support of the diver. Give your diver step-by-step instructions on the task he is to accomplish. At the same time organize and detail additional topside personnel so that the lines, the shackles, the tools, and the countless additional equipment will be ready to go to the diver the moment they are needed. Accomplish this work through subordinate petty officers with a minimum of confusion and you will be a good diving supervisor.

Additional Notes to the Diving Supervisor

(5) Make every effort to detail *all* routine work. Even when your responsibilities as the leader appear small, make it a habit to keep yourself above the minor jobs. You will find that you can always use time to review and improve your plans for the next phase. Most important, you must be ready for any contingency for which you haven't planned.

(6) There is an exception to the above general rule. In many instances a preliminary dive will be of great value in deciding on the correct course of action. Confine yourself to a preliminary dive and a final inspection dive, if they are necessary.

(7) Bear in mind that changing or unforeseen conditions may require changes in the original plan. To meet this possibility, you must have one or more alternative plans available. A successful plan must be flexible.

(8) Some of the most regrettable accidents in diving have resulted from a situation where diving operations have become routine. When the same type of diving is repeated day after day, there is a strong tendency to relax and lay aside the plans and preparations for emergencies. When you see this situation occurring, visualize the casualties that could happen. Hold an emergency drill, if necessary.

Preparations

(9) As outlined below, many important preparations must be made prior to the commencement of actual diving. The majority of these preparations will apply only to a particular type of diving apparatus or operation. Specific preparations applicable to surface-supplied diving and self-contained diving are covered in their respective sections in this manual.

(*a*) Insure that all necessary equipment is at the diving site.

(*b*) Check all equipment to insure proper operation.

(*c*) Insure that all who need to know are informed that diving operations are to commence.

(*d*) Provide an oxygen resuscitator, if available, at the scene of diving operations.

(*e*) Ascertain the location of nearest medical facilities and recompression chamber, and the availability of transportation to same.

(10) For additional guidance in preparations, refer to section 1.7.

Depth Limits

(11) Except in emergencies, or in exceptional circumstances, safe diving practices require limitations on the maximum depths and times of dives. These limitations shall not be exceeded except by specific authorization from the officer in charge of the diving operations or from higher authority. The following outline summarizes these limitations and in all cases refers to equipment approved and procured in accordance with Navy instructions.

Depth in feet:	*Limit for—*	*See notes—*
25	Breathing 100 percent oxygen while working or swimming	(*a*)
36	Nondesignated diver in an emergency situation	(*b*)
60	Open-circuit scuba; normal working limit	(*b*)
60	Lightweight diving equipment; normal working limit	(*b*)
90	Lightweight diving equipment; maximum working limit	(*b*)
130	Open-circuit scuba; maximum working limit	(*b*)
130	Nitrogen-oxygen mixed-gas scuba; normal working limit	(*c*) (*g*)
150	All divers except those qualified for mixed-gas diving	(*c*)
170	Nitrogen-oxygen mixed-gas scuba; exceptional exposure limit	(*g*)
170	Diving without a medical officer and a recompression chamber at the scene	(*d*) (*e*)
190	Surface-supplied deep-sea (air) diving; recommended working limit	(*e*)
200	Mixed-gas helium-oxygen scuba; maximum working limit	(*g*)
250	Surface-supplied deep-sea (air) diving; maximum working limit	(*d*) (*f*)
300	Surface-supplied, deep-sea, helium-oxygen diving; recommended working limit	(*d*) (*g*)
380	Surface-supplied, deep-sea, helium-oxygen diving; exceptional exposure limit	(*d*) (*g*)

NOTES

(*a*) For time limit at 25 feet and for other depth-time relationships, see 1.5.7.

(*b*) Do not exceed the "no-decompression" limits of table 1–11. Dives requiring decompression may be made if considered necessary by the officer in charge of the diving operations. The total time of a scuba dive (including decompression) must never exceed the duration of the apparatus in use, disregarding any reserves.

(*c*) Certain operational swimmers (EOD UDT) are authorized to dive to depths listed for use with mixed-gas scuba when required, provided they have been qualified through approved training.

(*d*) A diving medical officer and a recompression chamber are required on the scene for all dives deeper than 170 feet and for all dives using surface-supplied helium-oxygen equipment.

(*e*) Do not exceed the limits of table 1–10. Table 1–14 is computed for exceptional exposures and is intended only for exceptional and emergency situations. Such situations defy complete assurance of safety even if the table is used.

(*f*) Do not exceed the limits of table 1–14.

(*g*) These limits are based on a practical consideration of working time versus decompression time and oxygen-tolerance limits. In the use of nitrogen-oxygen mixed-gas scuba and surface-supplied helium, the limits of table 1–16 will not be exceeded except for exceptional situations.

1.4.2 THE DIVER

Qualification

(1) The diver must be qualified and designated in accordance with the information given in appendix F. The diving supervisor will check the diver's qualifications to insure that the diver is currently qualified for the type of apparatus to be used and for the work to be accomplished.

Condition

(2) The capability of diving equipment is limited by the capability of the man using the equipment, and the capability of the man is limited by his physical condition. It is imperative that the diver remain in good physical condition by means of training and proper medical attention. A complete physical examination prior to each dive is obviously impractical. The medical officer and corpsman should take an active personal interest in the condition of their men. The men should be encouraged to report any symptom or condition which might interfere with or prevent them from diving. A diver who, for any reason, seriously desires not to

make a certain dive should not be penalized or ridiculed. Psychological adjustment to diving and other specific duties should be assessed. The man who evidently dislikes diving or often demurs for insufficient reasons should be disqualified. The diving supervisor and medical officer should know their divers as individuals. This personal interest and relationship will contribute greatly toward keeping the divers both physically and mentally fit for diving.

(3) A high degree of physical fitness should be maintained for optimum performance. All diving activities, ships included, should establish a continuing physical training program and encourage such exercise as running, swimming, and skindiving. For any physical training to be beneficial, it must be continuous and consistent. Divers should have a well-balanced diet. Adequate sleep is imperative if the diver is to be efficient.

(4) The diving supervisor, with the aid of the medical officer and corpsman, must insure that the diver is fit to make a dive. He must—

(*a*) Determine that the diver feels fit.

(*b*) Prohibit diving with *any degree* of alcoholic intoxication or evidence of its aftereffects.

(*c*) Prohibit diving with respiratory or middle-ear disease.

(*d*) Prohibit diving with skin or external-ear infections.

Standby Diver and the Buddy System

(5) Any thorough preparations for a diving operation must include provisions for a standby diver or swim buddy, depending upon the type of diving apparatus employed. In an operation employing surface-supplied diving equipment, a *standby diver* must be designated. This diver must be dressed to the extent that he can enter the water almost immediately to go to the aid of the distressed diver. Standard deep-sea diving practice dictates that the standby diver be completely dressed except for weighted belt and helmet. When lightweight gear is being used, the same procedure must be followed if the dress is being worn. When provisions are being made for standby divers, it is important to visualize an emergency and to consider if help will reach the diver in time to be of material assistance.

(6) When self-contained diving equipment is being used, the buddy system is a necessity. Self-contained divers swimming or working as buddies must remain in sight of each other at all times and must be prepared to render assistance to each other as required. Under conditions of extremely low visibility, a buddy line should be used. A short length of line (preferably nylon) with a snap hook at each end makes a good buddy line.

1.4.3 EQUIPMENT

(1) Diving equipment is constantly being improved and changed as a result of new diving techniques. It is important that the modern diver keep abreast of equipment developments. The diving officer and the diver must know the capabilities and limitations of any equipment they use.

Selection (Appropriateness)

(2) Many factors are involved in determining the type of equipment to be employed on a job. The prime factor is the safety of the diver. To make the proper selection, the diving supervisor must be aware of the relative merits of surface-supplied equipment and self-contained gear. The capabilities and limitations of each type of gear can very often be the determining factor in deciding whether to use self-contained, shallow-water, or deep-sea rig.

(3) Before a job is started, an initial inspection dive should be made and the information obtained therefrom should be carefully evaluated. This intelligence will enable the diving supervisor to select the type of equipment to be used based on the conditions and the work to be performed.

Approved Equipment

(4) Diving equipment will not be used operationally unless it has received official evaluation and *approval*. Approved operational equipment will not be altered, modified, or changed in any way unless such modifications have been officially evaluated and *approved*. Trials of experimental gear and modification of present equipment may be conducted only at designated activities such as the Experimental Diving Unit, or at others when specifically authorized by the Naval Ship Systems Command. When evaluating new or modified equipment, the diving supervisor will give special

consideration to the safety of the personnel involved and will insure that all trials are properly supervised and safeguarded.

Maintenance

(5) The importance of proper maintenance cannot be overemphasized. Equipment must be in optimum condition at all times. A routine of periodic inspections and preventive maintenance for all equipment, regardless of its amount of use, must be established and adhered to rigidly. Diving equipment that is not in constant use is frequently susceptible to deterioration and damage. Records on all outfits and major components must be kept. Any defect, however minor, must be corrected before the equipment is used. An adequate supply of spare parts must be kept on hand. Maintenance, handling, and storage are covered in detail in chapter 2 for surface-supplied equipment and in chapter 3 for self-contained equipment. The schedules and precautions set forth in chapters 2 and 3 must be strictly adhered to by all diving activities.

1.4.4 DIVING CRAFT

General

(1) The *type* of craft utilized for any diving operation will depend upon the characteristics of the job and the diving apparatus to be used. In many diving operations it may not be feasible to work from the deck of a vessel; or the location of the operation may not be accessible to a large craft. In these cases, small craft which are adequately equipped to support the appropriate type of apparatus should be used. Small craft should also be used when the diving jobs will be of relatively short duration or will be performed at different points over a wide area. When a diving job entails months of diving in a small area, it may be convenient to build a diving float.

Surface-Supplied Diving Craft

(2) The diving equipment and diving personnel for surface-supplied diving are generally assigned to tenders, repair ships, salvage vessels, submarine rescue ships, diving barges or floats, or shore-based diving units. In diving operations where it is not feasible or practicable to work from one of these craft, any suitable small craft may be equipped or converted for diving. However, before any attempt is made to rig a small craft for diving, the following basic requirements must be considered:

(*a*) Adequate space for storage of equipment.

(*b*) Adequate space for diving platform.

(*c*) Adequate space for diving crew.

(*d*) Seaworthy hull.

(*e*) Engine in good condition.

(*f*) Adequate mast for display of diving hoist.

Scuba Diving Craft

(3) Self-contained divers, because of their mobility, are able to work from almost any type of craft. However, diving directly from large vessels or from the shore should be avoided, whenever possible. For an immediate base of operations, it is preferable to utilize a small power craft moored as close to the scene as possible. The craft must be able to cast off immediately to recover a diver in difficulty. The divers should be enabled to enter the water and return without difficulty through the use of a small ladder or stage. A line marked at 10-foot intervals should be rigged over the side to provide a convenient measure of decompression stops for the scuba divers. A seven-man rubber boat is an ideal diving craft because it can be used for a diving platform as well as for a recovery boat for the divers. There must be ample room for the diving crew to dress and for additional equipment to be stored. Provisions should be made to keep the divers warm and comfortable before and after dives.

1.4.5 SURFACE CONDITIONS

(1) In planning a *diving* operation, careful consideration must be given to the surface conditions that will be encountered at the scene of the operation. These conditions include the state of the sea, weather, tide, currents, presence of other ships, and any other surface conditions that could affect the operation.

(2) Upon arrival at the scene of the operation, local sea *conditions* must be studied to determine whether the diving craft can be moored and the divers put over the side. Diving operations must not be commenced in rough seas, unusual tides or currents, or any other conditions which in the opinion of the diving super-

visor might unnecessarily jeopardize the security of the divers. Working around or under small vessels is quite hazardous in rough seas.

(3) If divers are required to spend long periods in small craft under adverse sea conditions, seasickness can become a serious problem.

Other Ships

(4) If the diving operation is to be conducted in a crowded harbor or waterway, it might be necessary to have the immediate area cleared and patrolled. All ships in the vicinity must be notified of impending diving operations. Proper visual *signals* must be displayed in a prominent place on the diving craft during the operation to *warn other ships* or craft entering the area.

Visibility

(5) Except in an emergency, diving operations must not be conducted during periods of low visibility in any area where there is danger of the diving craft being struck by another vessel. The self-contained diver, when not tended from the *surface*, is particularly vulnerable in low *visibility* because he can become lost and is without means of relocating the diving craft.

Miscellaneous

(6) In diving, personnel on the surface (particularly on small craft) often suffer more from exposure than does the submerged diver. The effects of air temperature must be considered in extreme climates. Tenders may suffer from frostbite in a cold climate or from heat exhaustion in hot weather. Sunburn can be a serious problem, particularly if the men have not had the benefit of gradual exposure. The diving supervisor must consider the elements in planning his dives and must insure that all personnel have adequate clothing to protect them under the prevailing conditions.

(7) Readiness for accident and recompression are two important factors that must be considered in preparing for any diving operation. The presence of a recompression chamber and of a medical officer trained in diving are always desirable. Many occasions will arise, however, where neither is available. If neither is available and if diving is to be done at a depth which will require considerable decompression, the officer responsible for the operation must decide whether or not to proceed. Military necessity may at times require that diving be done in the absence of a recompression chamber or a medical officer. If there is a chamber nearby, the activity maintaining the chamber should be notified of the possible need for assistance so that the chamber will be ready if needed. A rapid means of transportation to the chamber should also be available. It is mandatory that a first-aid kit be available on all diving operations and, if feasible, a hospital corpsman should be present.

(8) Some thought should be given to surface communications before a job is commenced. On any diving operation there is the possibility of three general needs arising:

(*a*) Need for command decisions.

(*b*) Need for equipment and supplies.

(*c*) Need for medical services in case of accidents.

(9) If the supervisor permits himself and his crew to be isolated, considerable delay and confusion may be encountered when an unforeseen emergency arises. As a general rule, arrangements should be made to communicate with the following individuals:

(*a*) The officer in tactical command.

(*b*) The officer or activity who will supply additional tools, replacement parts, and food if needed.

(*c*) The activity having a medical officer trained in diving.

(*d*) The activity having a recompression chamber.

(*e*) The nearest medical facility having an ambulance.

1.4.6 UNDERWATER CONDITIONS

Depth

(1) Whether deep-sea, lightweight, or self-contained diving equipment should be used depends upon the depth of water as well as upon the purpose of the dive. Depth of water is, therefore, a basic consideration and should be determined accurately prior to the start of diving operations. This information is also necessary to determine what, if any, decompression is necessary. The effect of depth on light conditions under water is discussed in 1.2.9 (5 and 6).

(2) To determine depth accurately, use the pneumofathometer whenever feasible. The pneumofathometer consists of an oxygen hose of sufficient length to reach the depth to be measured, an air supply of greater pressure than the maximum depth, and an accurate gage. Both the air supply and the gage are connected to the surface end of the hose. To use the pneumofathometer, leave the hose open at the bottom end and submerge it to the depth to be measured. Do this by attaching the hose to a diver or to a weighted object. When the bottom end of the hose is positioned, blow out the hose with the air supply. Secure the air supply and read the depth on the gage.

Bottom Conditions

(3) Bottom conditions have a decided effect on a diver's ability to move about and on his ability to see. In general there are six main types of bottoms, all of which will be described individually.

(*a*) *Rock*.—This type of bottom may be either smooth or jagged. If the latter is the case, care must be used to keep lines from getting caught on protruding rocks or wreckage. Deep-sea divers have no difficulty in walking on this type of bottom, although they must be careful not to fall from ledges. If a diver is confronted with an obstruction or wreckage, it is better to go over it than around it. However, if it becomes necessary to go around such an obstruction, the diver should note carefully on which side he is passing so that he can avoid returning on the wrong side. Visibility is not impaired by sediment stirred up as the diver walks on this type of bottom.

(*b*) *Coral*.—Coral bottoms are solid but are practically always jagged. The diver normally has no difficulty in moving, but gloves are recommended to protect the hands from the sharp and painful cuts which result from contact with this type bottom. As with jagged rock, great care should be taken to prevent fouling of the air and lifelines and to prevent falling. Visibility is not impaired by bottom conditions.

(*c*) *Gravel*.—Gravel bottoms normally provide a good base for the diver, permitting easy movement and a relatively smooth, flat surface. Occasionally, a diver will encounter sloping bottoms with loose gravel. These bottoms are often difficult to walk on because such gravel frequently causes the diver to slip and fall. As with rock and coral, visibility is little affected by the diver's movements on the bottom.

(*d*) *Shell*.—Bottoms composed principally of broken shells are sometimes encountered. The shells are usually mixed with sand or mud. Where a shell-sand mixture exists, the diver's movements are not impaired and visibility is little affected by movement. A shell-mud mixture is more susceptible to penetration. The degree to which a diver will sink into the bottom depends upon the amount of mud present. Visibility is affected because the mud is stirred up and clouds the water. As the proportion of mud increases, the diver will find it increasingly difficult to see and to move.

(*e*) *Sand*.—Many bottoms are composed mainly of sand. Sand packs hard, and even if other materials are present they are usually packed in with the sand. The diver, therefore, can walk freely on this type of bottom, and visibility is normally not impaired.

(*f*) *Mud*.—Mud is composed of silt and clay in varying amounts. This very common type bottom restricts a diver's movements. The fact that a diver sinks into mud up to his knees, waist, or even over his head is not a serious matter. He may easily escape by inflating his suit and wiggling loose. It is difficult to walk on such a bottom; and crawling, assisted by proper and periodic inflation of the diving suit to decrease negative buoyancy, may be the only possible way to move. Because the slightest movement will stir up the sediment and cause clouds of mud which decrease visibility, movement in mud should be curtailed as much as possible. The diver should orient himself so that the current, if any, will carry the silt away from his work. The only hazard involved in diving in mud is the inability to see such objects as wreckage, pilings, and other types of debris. The self-contained diver has a decided advantage on a mud bottom because he can work and move about without touching the bottom and stirring up mud. Thus his visibility is better. However, visibility is often quite limited near a mud bottom even if the bottom has not been stirred up.

(4) Harbor and channel areas of the continental United States are usually sandy, al-

though mud bottoms exist in many of these areas.

Tides and Currents

(5) A diver at 50 feet of depth can barely feel the wave motion of surface waves having a length of 100 feet. Wave motion becomes more noticeable as the waves increase in height or as the diver moves into shallower water.

(6) There are various types of currents the diver may encounter, and they will have an effect upon all divers regardless of the diving equipment worn. The deep-sea diver wearing a lifeline and heavy weights will be less affected by currents, and will be able to work in stronger currents than will the diver wearing self-contained diving gear. Ripcurrents are seaward-moving streams that return the water carried shoreward by waves. These currents often reach 2 knots and usually extend 1,000 feet to one-half of a mile offshore. These currents are of concern primarily to the self-contained diver. Other than local inshore currents, divers will also encounter currents caused by tides and other factors. If understood, they can be used to the diver's advantage. Because current direction and velocity will vary with depth, tide, and bottom configuration, current tables must be used with caution as they show only surface conditions. Normally, current velocity decreases with depth. In many places where tidal currents are rapid, it may be necessary to limit diving time to periods of slack water. The strongest current speeds in which a deep-sea diver can do useful work vary from 2 to 2.5 knots. A self-contained diver is handicapped by even a small current of less than 1 knot. An additional heavy-weighted belt will be necessary for divers in currents of 1.5 knots and above.

Visibility

(7) The effects created by light after it enters water have previously been discussed. The fine particles suspended in water are called *debris* and consist of fragments of organic matter or mud. Pure water is transparent, but when debris is present the water becomes turbid and objects disappear as in a fog. Underwater visibility varies, depending on the locality, general water condition, and type of bottom. In tropical waters, visibility is usually quite good, and it is frequently possible to see more than 100 feet at 30 fathoms' depth. Channel and harbor areas are usually quite turbid because the sediment-laden rivers empty into these areas. Ships and strong currents passing through a channel often stir up the bottom. Visibility in such areas is frequently zero and seldom more than 15 to 20 feet maximum. Rainy seasons and plankton, which increase in spring and fall, also contribute to a decrease in visibility.

Temperature

(8) Divers are extremely sensitive to a change in *temperature* because *water* is a better heat conductor than air. Heat prostration can occur in water above 86° F if the diver is working. Heat prostration can be expected in water above 96° F even if the diver is at rest. Although there is no diving equipment at present that will protect a diver against heat, a regular deep-sea dress will provide considerable protection against cold water. If the dress has no leaks, and if heavy woolen underwear and gloves are worn, the diver can work in water of any degree of coldness. One possible problem, however, is freezing of the moisture in the diver's air hose. Care must be taken to prevent the air hose from becoming blocked. Protective dress is always necessary for scuba divers in water colder than 60° F, or in water colder than 68° to 70° F if the diver will be submerged for more than an hour. When a diver becomes uncomfortably cold, his ability to concentrate and his efficiency drop off rapidly.

1.4.7 THE DIVE

(1) Although procedures vary greatly depending on the type of equipment used, certain basic procedures apply to all types of diving. No matter what conditions are encountered or what equipment is used, all divers are acted upon by the same weight of water and encounter the same problems of breathing gases under pressure. Specific diving procedures for the various types of equipment are discussed in detail in the applicable sections of the manual.

Diving Signals

(2) The three basic means of communication used by divers are visual communications, voice communications, and line-pull signals. Visual communications are limited to conditions of

good visibility and therefore are most applicable to scuba diving. Visual communication may be accomplished by writing on a slate, by hand signals, or by any easily understandable gesture. A system of hand signals designed for scuba diving is presented in 3.2.2.

(3) It is possible for divers to talk to each other directly if they are close enough to each other, but the conversation is difficult to interpret (1.2.9(10)). Electrical means of voice communication prove more satisfactory, particularly when deep-sea diving equipment is used. Electrical means of voice communication are being developed for diving in self-contained and lightweight equipment. Specific procedures for the use of the diver's intercom are contained in appendix C.

(4) Line-pull signals remain the basic means of communication whenever the diver is connected to the surface by a lifeline. Line-pull signals are not affected by conditions of visibility or by electrical equipment failures and are therefore the most dependable means of communication for any type of diving. Line-pull signals have been standardized for the Navy, and their use must be understood by all Navy divers. Special signals for particular operations may also be arranged between the diver and the tender. Special signals applicable only to helium-oxygen diving are included in chapter 2 of this manual.

(5) Line-pull signals consist of a series of sharp, distinct pulls, strong enough for the diver or tender to feel but not so strong as to pull the diver away from his work. When sending signals, take all slack out of the line first. Repeat signals until answered. Continued failure by a diver to answer a signal may indicate too much slack in the line, a fouled line, or an accident to the diver. Notify the supervisor immediately if the diver fails to respond. (The problem of loss of communication is covered in 1.6.16.) Signals are answered when received, with two exceptions. Answering the emergency signal "haul me up" results in too much loss of time. Also, the diver never answers the signal "come up" until he is ready to leave the bottom. If he is unable to leave the bottom at that time, he communicates that fact by intercom or by use of the "I understand you" signal followed (if necessary) by the applicable emergency signal. Many of the standard line-pull signals may be used not only on the lifeline and air hose but also on any other line with which the diver is working.

(6) Signals from tender to diver:

Signal:	*Meaning*
1 pull	Are you all right? (When diver is descending, 1 pull means stop.)
2 pulls	Going down. (During ascent, you have come up too far. Go back down until I stop you.)
3 pulls	Stand by to come up.
4 pulls	Come up.
2–1 pulls	I understand, *or* answer the telephone.

(7) Signals from diver to tender:

Signal:	*Meaning*
1 pull	I am all right.
2 pulls	Give me slack, *or* lower me.
3 pulls	Take up my slack.
4 pulls	Haul me up.
2–1 pulls	I understand, *or* answer the telephone.
3–2 pulls	Give me more air.
4–3 pulls	Give me less air.

(8) Emergency signals from the diver:

Signal:	*Meaning*
2–2–2 pulls	I am fouled and need the assistance of another diver.
3–3–3 pulls	I am fouled but can clear myself.
4–4–4 pulls	Haul me up immediately.

The diving supervisor must try to discover the nature of any emergency as soon as possible, because in some cases it may be necessary to bring the diver to the surface with decompression.

(9) Searching signals are employed so that the tender can direct the diver as he moves along the bottom. A seven-pull signal from the tender to the diver means that the diver will interpret the succeeding signals as searching signals. A seven-pull signal to a diver who is already using searching signals means that these are to be used no longer. Only the tender may originate searching signals. It is not necessary for a diver to terminate searching signals before originating another signal, as no signal from the diver will be interpreted as a searching signal. To interpret the direction in which

he is ordered to move, the diver will face or will assume he is facing the lifeline (or the descending line if he is using a circling line attached to the descending weight). In sending signals to the diver, the tender must take into consideration the diver's position in relation to his lifeline or descending weight.

Searching Signals

Signal:	*Meaning*
1 pull	Stop and search where you are.
2 pulls	Move directly away from the tender if given slack. Move toward the tender if a strain is taken on the lifeline. If using the circling line, move away from the weight.
3 pulls	Move to your right.
4 pulls	Move to your left.

(10) Use the following procedure when working with lines on the bottom. To send a relatively light object to the surface, the diver signals 1–2–3 pulls, which means "send me a square mark." The tender attaches a short piece of line, approximately 3 feet long, to the lifeline and then signals three pulls, meaning "take up the slack." The diver hauls in the slack until he reaches the square mark, he then signals one pull, which means "stop." After he has attached the object to be lifted to his lifeline with the square mark, he signals three pulls, meaning "take up the slack." When the object reaches the surface, the tender detaches it from the lifeline and signals one pull ("are you all right?"). All signals are answered as sent. The procedure for lifting a heavier object is similar. The diver signals five pulls ("send me a line"). The tender selects a line adequate for the weight to be lifted and bends the bitter end to the lifeline. When the tender signals three pulls, the diver takes up the slack until the bitter end of the line is in hand. After signaling one pull ("stop"), he removes the line from his lifeline and signals three pulls on his lifeline. When the tender has taken all the slack out of the lifeline, he signals one pull ("are you all right?"). The diver then makes the line fast to the object to be lifted and commences signaling. Signals used on the line are: one pull, "stop lifting"; two pulls, "slack the line"; three pulls, "take up the slack"; and four pulls, "haul it up." All pulls, whether on the lifeline or any other line, are answered as received.

Tending the Diver

(11) From the time diving operations are first planned, the thoroughness with which the tenders understand and carry out their duties will, to a considerable extent, determine the success or failure of the operation and the safety of the diver. Tenders will be experienced divers. The most effective assistance can be given only by a tender who is familiar with the equipment, safety precautions, conditions, and difficulties that are inherent in diving. Only in cases of emergency will a nondiver be used as a tender; in those cases it will then be the duty of the diving officer to see that the personnel temporarily designated as *tenders* are properly instructed and supervised in their topside duties. It is the tender's responsibility and duty to insure that the diver receives proper care while topside and while submerged. Before sending the diver down, the tender must thoroughly check all equipment for proper operation.

(12) Generally, the topside duties consist of handling communications, tending lines, and insuring an adequate flow of air. The usual means of communication between diver and tender is by intercom. However, it is important that the basic hand signals listed in the preceding paragraphs, plus any supplementary signals originated to fit a particular type of job, be memorized and practiced so they will be recognized instantly in the event of intercom failure or if gear not fitted with an intercom is used.

(13) The tender must always keep himself informed as to the depth of the diver. Inasmuch as fathometers, lead lines, descending lines, stage lines, or payed-out lifeline and air hose cannot be used to determine depth with accuracy, a simple and accurate device called a pneumofathometer has been developed. Depth is determined by means of an air supply, a depth gage calibrated in feet of sea water, and an oxygen hose. This oxygen hose is attached to the diver's lifeline and air hose, its open end terminating at about the breastplate level. In self-contained diving it may be hung on a weight. To take a reading, air is blown through

the hose until it escapes at the open end, and then the air supply is secured. The pressure remaining in the oxygen hose is that necessary to balance a column of water corresponding to the depth of the open end of the hose; this pressure is read directly on the gage in feet. If the diver is standing, 5 feet are added to the gage reading to determine bottom depth. This device is especially valuable in determining decompression stops during ascent when the diver has been swept from the descending line.

(14) The tender should frequently contact the diver by intercom or hand signal while the diver is on the bottom and on the stage to ascertain if all is well. The tender must give the diver a few minutes' notice before the expiration of the diver's time on the bottom, so that the diver can make the necessary preparation prior to his ascent and not exceed the limit of his stay on the bottom.

The Timekeeper

(15) The diving officer or supervisor must appoint a qualified *diver* as *timekeeper.* The timekeeper must keep an accurate record of the time required for the diver to reach the bottom, the depth of dive, the time of exposure on the bottom, the time of ascent to the first stop, and the time spent at each subsequent stop during the ascent. These data must be carefully kept and recorded in the diving log. The timekeeper must at all times have the Navy Standard Decompression Tables (1.5.2) at hand and must be prepared at any moment to advise the diving supervisor or tenders as to the decompression procedure to be used. In case of doubt or of borderline determinations of decompression procedure, he must decide in the diver's favor (i.e., choose the next deeper table or next longer time of dive). If a predetermined bottom time has been planned for the dive, the timekeeper must be sure to notify the tender and supervisor well in advance so that the diver may be brought up on schedule. No additional duties may be assigned to a timekeeper if they in any way interfere with or distract his attention from his primary duty. He may, however, be assigned such additional duty as observing the diver's air-supply pressure. A timekeeper will not normally be required to keep time on more than two divers at once.

Entering the Water

(16) Before the diver enters the water, the diving supervisor must insure that all *equipment* is *working properly* and that the diver knows exactly what task he must perform. The depth of the water must be accurately determined by a lead line or some other reliable means. The standby diver or buddy must be ready. Proper preparation or briefing will save considerable time and effort and may make the difference between a successful job and a complete failure. If a lifeline to the surface is used, the tender must also be properly briefed. An experienced tender can tell a great deal about the diver's progress and problems by the feel of the lifeline. Because of the diver's limited efficiency and time, the job should be planned so that all possible work is done on the surface.

(17) Proper *procedures* for *entering* the water depend on the equipment being used and are covered in the applicable sections of this manual. The rule of "look before you leap" applies to all diving. Landing on another diver's head can be painful to all concerned. Before a diver leaves the surface, a final check must be made to see that all equipment is working properly. All the equipment must be functioning properly before the diver leaves the surface.

(18) The *descent* should be made as rapidly as possible (but should not exceed 75 feet per minute), provided that the diver is in complete control of the rate of descent. An uncontrolled descent can result in squeeze, ruptured eardrums, or injury from hitting objects on the bottom. The rate of descent will depend on the diver's experience, the type of gear worn, the conditions of visibility, and the diver's ability to equalize the pressure in his ears and sinuses. If the pressure is not equalized, continued descent will result in a ruptured eardrum. A diver should never continue to descend if he is unable to equalize the pressure. Pain in the ears may be relieved by yawning, swallowing, or blocking the nostrils and making a strong effort to exhale. Ascending a few feet will also relieve the pain in most cases. If these remedies do not succeed in equalizing the pressure in the ears and in relieving the pain, the diver must return to the surface and should not dive again during the same day.

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Working on the Bottom

(19) After reaching the bottom, the diver should ventilate and should make any necessary adjustments to his breathing supply and his buoyancy to adapt himself to conditions on the bottom. A few minutes should also be spent in considering the work from all angles and in planning the method to be used. No matter how thorough the topside briefing, the final plan of attack must always be the decision of the diver. An experienced diver can make his work much easier by proper use of his equipment. For instance, a deep-sea diver can lift heavy weights on the bottom by hooking his arms under the object to be lifted and holding his helmet air-regulating exhaust-valve stem (chin button). The increase in buoyancy of his suit does most of the work. Specific techniques depend on the equipment used and may be found in the applicable parts of the manual.

(20) When working on the bottom, the diver must never become so engrossed in his work that he forgets about his own condition. It is possible to work to the point of exhaustion on the bottom without realizing it. Failing to pay attention to the condition of the air supply may easily result in unconsciousness.

Ascent

(21) After completing his task, the diver prepares to ascend. This preparation may involve sending tools to the surface, a final inspection of the job, and clearing any fouled lifeline or air hose. The diver must never ignore the tender's signal to ascend. At times it is a strong temptation to remain on the bottom a few more minutes to complete a task, but the tender is aware of conditions which the diver himself is unable to see, and he must be obeyed. If the diver is unable to come to the surface because of fouled lines or any other cause, he should make the situation known to the tender by any possible means. The tender, on the other hand, must never ignore the diver's signal to haul him up. The rate of ascent must be under control at all times. Excess speed of ascent can result in blowing up because of overexpansion of air in the deep-sea outfit.

NOTE

Blowup is a serious accident. It is discussed in detail in 1.6.10.

(22) In all dives employing the air decompression tables, regardless of the type of equipment being used, ascent must be at the rate of 60 feet per minute. For any variations in rate of ascent, see table 1–9.

NOTE

When the table for *surface decompression using oxygen* is employed, a rate of ascent of *25 feet per minute* must be used.

(23) The necessity for *decompression* depends upon the time and depth of the dive. Extremely cold dives and those involving exceptionally hard work require additional decompression. Careful planning of bottom time and decompression time is necessary, particularly where the air supply is limited, as in the case of the scuba diver. A scuba diver must know the required decompression time before he makes his dive and must have a means of keeping track of time and depth. A descending line plainly marked at 10-foot intervals should be used for decompression of the scuba diver. For surface-supplied diving, the lifeline should be marked so that the tender can know the diver's depth. When long decompression stops are necessary, a decompression stage should be used so that the diver may rest while decompressing. When the stage is used, the line should be marked to the stage to determine the diver's depth.

(24) In case of *emergency* it may be necessary to bring the diver to the *surface* before he has completed his decompression. (See 1.5.6 for the management of such situations.) In any emergency, it is the responsibility of the diving supervisor to weigh the danger of decompression sickness against the hazard of remaining submerged. The problem is particularly serious when no recompression chamber is available. The detailed procedure of decompression is explained in table 1–9.

(25) The chief danger for the diver in surfacing is that he may come up under the diving boat or float, with resulting damage to the head. The possibility of injury of this nature

exists in all diving, but is most serious in self-contained diving. Fortunately, the self-contained diver is, in most cases, better able to see what is above him, and with reasonable care he can avoid injury.

(26) After completing a dive, the diver should remain in the vicinity of the recompression chamber or the facility for underwater recompression for at least 1 hour. This time should be extended to 12 hours for any dive requiring recompression.

(27) A dive performed within 12 hours of surfacing from a previous dive is a repetitive dive. Limit the equivalent single dive schedule of repetitive dives to table 1–10. No repetitive dives falling within the limits of table 1–14 are permitted, nor are repetitive helium-oxygen dives with surface-supplied equipment.

SECTION 1.5 DIVING TABLES

1.5.1 GENERAL

The tables and procedures outlined herein have been developed to provide safety from the hazards of decompression sickness and oxygen toxicity described in section 1.3. At the same time, the tables have been made as efficient as possible in order that they will be the least possible hindrance to diving operations.

1.5.2 AIR DECOMPRESSION TABLES

General

(1) The air decompression tables are comprised of—

(*a*) Decompression Procedures (table 1–9).

(*b*) U.S. Navy Standard Air Decompression Table (table 1–10).

(*c*) No-Decompression Limits and Repetitive Groups (table 1–11).

(*d*) Surface Interval Credit Table (table 1–12).

(*e*) Repetitive Dive Timetable (table 1–13).

(*f*) Standard Air Decompression Table for Exceptional Exposures (table 1–14).

(2) For all dives where air is the breathing medium, regardless of the type of diving apparatus, use these tables as prescribed.

(3) Use these tables in conjunction with the Equivalent Air Tables (table 1–15) for dives where a nitrogen-oxygen mixture is the breathing medium.

(FORMERLY TABLE 1–4, 1963 DIVING MANUAL)

TABLE 1–9.—*Decompression procedures*

GENERAL INSTRUCTIONS FOR AIR DIVING

Need for Decompression

A quantity of nitrogen is taken up by the body during every dive. The amount absorbed depends upon the depth of the dive and the exposure (bottom) time. If the quantity of nitrogen dissolved in the body tissues exceeds a certain critical amount, the ascent must be delayed to allow the body tissue to remove the excess nitrogen. Decompression sickness results from failure to delay the ascent and to allow this process of gradual desaturation. A specified time at a specific depth for purposes of desaturation is called a decompression stop.

No-Decompression Schedules

Dives that are not long or deep enough to require decompression stops are no-decompression dives. Dives to 33 feet or less do not require decompression stops. As the depth increases, the allowable bottom time for no-decompression dives decreases. Five minutes at 190 feet is the deepest no-decompression schedule. These dives are all listed in the *No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Dives* (No-Decompression Table (table 1–11)), and only require compliance with the 60-feet-per-minute rate of ascent.

Schedules That Require Decompression Stops

All dives beyond the limits of the *No-Decompression Table* require decompression stops. These dives are listed in the *Navy Standard Air Decompression Table* (table 1–10). Comply exactly with instructions except as modified by surface decompression procedures.

Variations in Rate of Ascent

Ascend from all dives at the rate of 60 feet per minute.

In the event you are unable to maintain the 60-feet-per-minute rate of ascent:

(*a*) If the delay was at a depth greater than 50 feet: increase the bottom time by the difference between the time used in ascent and the time that should have been used at a rate of 60 feet per minute. Decompress according to the requirements of the new total bottom time.

(*b*) If the delay was at a depth less than 50 feet: increase the first stop by the difference between the time used in ascent and the time that should have been used at the rate of 60 feet per minute.

Repetitive Dive Procedure

A dive performed within 12 hours of surfacing from a previous dive is a repetitive dive. The period between dives is the surface interval. Excess nitrogen requires 12 hours to be effectively lost from the body. These tables are designed to protect the diver from the effects of this residual nitrogen. Allow a minimum surface interval of 10 minutes between all dives. For any interval under 10 minutes, add the bottom time of the previous dives to that of the repetitive dive and choose the decompression schedule for the total bottom time and the deepest dive. Specific instructions are given for the use of each table in the following order:

(1) The *No-Decompression Table* or the *Navy Standard Air Decompression Table* gives the repetitive group designation for all schedules which may precede a repetitive dive.

(2) The *Surface Interval Credit Table* gives credit for the desaturation occurring during the surface interval.

(3) The *Repetitive Dive Timetable* gives the number of minutes of residual nitrogen time to add to the actual bottom time of the repetitive dive to obtain decompression for the residual nitrogen.

(4) The *No-Decompression Table* or the *Navy Standard Air Decompression Table* gives the decompression required for the repetitive dive.

U.S. NAVY STANDARD AIR DECOMPRESSION TABLE

Instructions for Use

Time of decompression stops in the table is in minutes.

Enter the table at the exact or the next greater depth than the maximum depth attained during the dive. Select the listed bottom time that is exactly equal to or is next greater than the bottom time of the dive. Maintain the diver's chest as close as possible to each decompression depth for the number of minutes listed. The rate of ascent *between* stops is not critical for stops of 50 feet or less. Commence timing each stop on arrival at the decompression depth and resume ascent when the specified time has lapsed.

For example—a dive to 82 feet for 36 minutes. To determine the proper decompression procedure: The next greater depth listed in this table is 90 feet. The next greater bottom time listed opposite 90 feet is 40. Stop 7 minutes at 10 feet in accordance with the 90/40 schedule.

For example—a dive to 110 feet for 30 minutes. It is known that the depth did not exceed 110 feet. To determine the proper decompression schedule: The exact depth of 110 feet is listed. The exact bottom time of 30 minutes is listed opposite 110 feet. Decompress according to the 110/30 schedule unless the dive was particularly cold or arduous. In that case, go to the schedule for the next deeper and longer dive, i.e., 120/40.

(FORMERLY TABLE 1-5, 1963 DIVING MANUAL)

TABLE 1-10.—*U.S. Navy Standard Air Decompression Table*

Depth (feet)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent (min:sec)	Repetitive group
			50	40	30	20	10		
40	200						0	0:40	(*)
	210	0:30					2	2:40	N
	230	0:30					7	7:40	N
	250	0:30					11	11:40	O
	270	0:30					15	15:40	O
	300	0:30					19	19:40	Z
50	100						0	0:50	(*)
	110	0:40					3	3:50	L
	120	0:40					5	5:50	M
	140	0:40					10	10:50	M
	160	0:40					21	21:50	N
	180	0:40					29	29:50	O
	200	0:40					35	35:50	O
	220	0:40					40	40:50	Z
	240	0:40					47	47:50	Z

TABLE 1-10.—*U.S. Navy Standard Air Decompression Table*—Continued

Depth (feet)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent (min:sec)	Repetitive group
			50	40	30	20	10		
60	60						0	1:00	(*)
	70	0:50					2	3:00	K
	80	0:50					7	8:00	L
	100	0:50					14	15:00	M
	120	0:50					26	27:00	N
	140	0:50					39	40:00	O
	160	0:50					48	49:00	Z
	180	0:50					56	57:00	Z
	200	0:40				1	69	71:00	Z
70	50						0	1:10	(*)
	60	1:00					8	9:10	K
	70	1:00					14	15:10	L
	80	1:00					18	19:10	M
	90	1:00					23	24:10	N
	100	1:00					33	34:10	N
	110	0:50				2	41	44:10	O
	120	0:50				4	47	52:10	O
	130	0:50				6	52	59:10	O
	140	0:50				8	56	65:10	Z
	150	0:50				9	61	71:10	Z
	160	0:50				13	72	86:10	Z
	170	0:50				19	79	99:10	Z
80	40						0	1:20	(*)
	50	1:10					10	11:20	K
	60	1:10					17	18:20	L
	70	1:10					23	24:20	M
	80	1:00				2	31	34:20	N
	90	1:00				7	39	47:20	N
	100	1:00				11	46	58:20	O
	110	1:00				13	53	67:20	O
	120	1:00				17	56	74:20	Z
	130	1:00				19	63	83:20	Z
	140	1:00				26	69	96:20	Z
	150	1:00				32	77	110:20	Z
90	30						0	1:30	(*)
	40	1:20					7	8:30	J
	50	1:20					18	19:30	L
	60	1:20					25	26:30	M
	70	1:10				7	30	38:30	N
	80	1:10				13	40	54:30	N
	90	1:10				18	48	67:30	O
	100	1:10				21	54	76:30	Z
	110	1:10				24	61	86:30	Z
	120	1:10				32	68	101:30	Z
	130	1:00			5	36	74	116:30	Z
100	25						0	1:40	(*)
	30	1:30					3	4:40	I
	40	1:30					15	16:40	K
	50	1:20				2	24	27:40	L
	60	1:20				9	28	38:40	N
	70	1:20				17	39	57:40	O
	80	1:20				23	48	72:40	O
	90	1:10			3	23	57	84:40	Z

TABLE 1-10.—*U.S. Navy Standard Air Decompression Table*—Continued

Depth (feet)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent (min:sec)	Repetitive group
			50	40	30	20	10		
100—Continued	100	1:10			7	23	66	97:40	Z
	110	1:10			10	34	72	117:40	Z
	120	1:10			12	41	78	132:40	Z
110	20						0	1:50	(*)
	25	1:40					3	4:50	H
	30	1:40					7	8:50	J
	40	1:30				2	21	24:50	L
	50	1:30				8	26	35:50	M
	60	1:30				18	36	55:50	N
	70	1:20			1	23	48	73:50	O
	80	1:20			7	23	57	88:50	Z
	90	1:20			12	30	64	107:50	Z
	100	1:20			15	37	72	125:50	Z
120	15						0	2:00	(*)
	20	1:50					2	4:00	H
	25	1:50					6	8:00	I
	30	1:50					14	16:00	J
	40	1:40				5	25	32:00	L
	50	1:40				15	31	48:00	N
	60	1:30			2	22	45	71:00	O
	70	1:30			9	23	55	89:00	O
	80	1:30			15	27	63	107:00	Z
	90	1:30			19	37	74	132:00	Z
	100	1:30			23	45	80	150:00	Z
130	10						0	2:10	(*)
	15	2:00					1	3:10	F
	20	2:00					4	6:10	H
	25	2:00					10	12:10	J
	30	1:50				3	18	23:10	M
	40	1:50				10	25	37:10	N
	50	1:40			3	21	37	63:10	O
	60	1:40			9	23	52	86:10	Z
	70	1:40			16	24	61	103:10	Z
	80	1:30		3	19	35	72	131:10	Z
	90	1:30		8	19	45	80	154:10	Z
140	10						0	2:20	(*)
	15	2:10					2	4:20	G
	20	2:10					6	8:20	I
	25	2:00				2	14	18:20	J
	30	2:00				5	21	28:20	K
	40	1:50			2	16	26	46:20	N
	50	1:50			6	24	44	76:20	O
	60	1:50			16	23	56	97:20	Z
	70	1:40		4	19	32	68	125:20	Z
	80	1:40		10	23	41	79	155:20	Z
150	5						0	2:30	C
	10	2:20					1	3:30	E
	15	2:20					3	5:30	G
	20	2:10				2	7	11:30	H
	25	2:10				4	17	23:30	K
	30	2:10				8	24	34:30	L
	40	2:00			5	19	33	59:30	N
	50	2:00			12	23	51	88:30	O

TABLE 1-10.—*U.S. Navy Standard Air Decompression Table*—Continued

Depth (feet)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent (min:sec)	Repetitive group
			50	40	30	20	10		
150—Continued	60	1:50		3	19	26	62	112:30	Z
	70	1:50		11	19	39	75	146:30	Z
	80	1:40	1	17	19	50	84	173:30	Z
160	5						0	2:40	D
	10	2:30					1	3:40	F
	15	2:20				1	4	7:40	H
	20	2:20				3	11	16:40	J
	25	2:20				7	20	29:40	K
	30	2:10			2	11	25	40:40	M
	40	2:10			7	23	39	71:40	N
	50	2:00		2	16	23	55	98:40	Z
	60	2:00		9	19	33	69	132:40	Z
	70	1:50	1	17	22	44	80	166:40	Z
170	5						0	2:50	D
	10	2:40					2	4:50	F
	15	2:30				2	5	9:50	H
	20	2:30				4	15	21:50	J
	25	2:20			2	7	23	34:50	L
	30	2:20			4	13	26	45:50	M
	40	2:10		1	10	23	45	81:50	O
	50	2:10		5	18	23	61	109:50	Z
	60	2:00	2	15	22	37	74	152:50	Z
	70	2:00	8	17	19	51	86	183:50	Z
180	5						0	3:00	D
	10	2:50					3	6:00	F
	15	2:40				3	6	12:00	I
	20	2:30			1	5	17	26:00	K
	25	2:30			3	10	24	40:00	L
	30	2:30			6	17	27	53:00	N
	40	2:20		3	14	23	50	93:00	O
	50	2:10	2	9	19	30	65	128:00	Z
	60	2:10	5	16	19	44	81	168:00	Z
190	5						0	3:10	D
	10	2:50				1	3	7:10	G
	15	2:50				4	7	14:10	I
	20	2:40			2	6	20	31:10	K
	25	2:40			5	11	25	44:10	M
	30	2:30		1	8	19	32	63:10	N
	40	2:30		8	14	23	55	103:10	O
	50	2:20	4	13	22	33	72	147:10	Z
	60	2:20	10	17	19	50	84	183:10	Z

*See table 1-11 for repetitive groups in no-decompression dives.

(FORMERLY TABLE 1-6, 1963 DIVING MANUAL)

TABLE 1-11.—*No-decompression limits and repetitive group designation table for no-decompression air dives*

Depth (feet)	No-decompression limits (min)	Repetitive groups (air dives)														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10	-----	60	120	210	300	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
15	-----	35	70	110	160	225	350	-----	-----	-----	-----	-----	-----	-----	-----	-----
20	-----	25	50	75	100	135	180	240	325	-----	-----	-----	-----	-----	-----	-----
25	-----	20	35	55	75	100	125	160	195	245	315	-----	-----	-----	-----	-----
30	-----	15	30	45	60	75	95	120	145	170	205	250	310	-----	-----	-----
35	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270	310
40	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200	-----
50	100	-----	10	15	25	30	40	50	60	70	80	90	100	-----	-----	-----
60	60	-----	10	15	20	25	30	40	50	55	60	-----	-----	-----	-----	-----
70	50	-----	5	10	15	20	30	35	40	45	50	-----	-----	-----	-----	-----
80	40	-----	5	10	15	20	25	30	35	40	-----	-----	-----	-----	-----	-----
90	30	-----	5	10	12	15	20	25	30	-----	-----	-----	-----	-----	-----	-----
100	25	-----	5	7	10	15	20	22	25	-----	-----	-----	-----	-----	-----	-----
110	20	-----	-----	5	10	13	15	20	-----	-----	-----	-----	-----	-----	-----	-----
120	15	-----	-----	5	10	12	15	-----	-----	-----	-----	-----	-----	-----	-----	-----
130	10	-----	-----	5	8	10	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
140	10	-----	-----	5	7	10	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
150	5	-----	-----	5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
160	5	-----	-----	-----	5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
170	5	-----	-----	-----	5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
180	5	-----	-----	-----	5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
190	5	-----	-----	-----	5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Instructions for Use

I. No-decompression limits:

This column shows at various depths greater than 30 feet the allowable diving times (in minutes) which permit surfacing directly at 60 feet a minute with no decompression stops. Longer exposure times require the use of the Standard Air Decompression Table (table 1-10).

II. Repetitive group designation table:

The tabulated exposure times (or bottom times) are in minutes. The times at the various depths in each vertical column are the maximum exposures during which a diver will remain within the group listed at the head of the column.

To find the repetitive group designation at surfacing for dives involving exposures up to and including the no-decompression limits: Enter the table on the *exact or next greater depth* than that to which exposed and select the listed exposure time *exact or next greater* than the actual exposure time. The repetitive group designation is indicated by the letter at the head of the vertical column where the selected exposure time is listed.

For example: A dive was to 32 feet for 45 minutes. Enter the table along the 35-foot-depth line since it is next greater than 32 feet. The table shows that since group D is left after 40 minutes' exposure and group E after 50 minutes, group E (at the head of the column where the 50-minute exposure is listed) is the proper selection.

Exposure times for depths less than 40 feet are listed only up to approximately 5 hours since this is considered to be beyond field requirements for this table.

(FORMERLY TABLE 1-7, 1963 DIVING MANUAL)

TABLE 1-12.—*Surface Interval Credit Table for air decompression dives*

[Repetitive group at the end of the surface interval (air dive)]

Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
0:10 0:22	0:23 0:34	0:35 0:48	0:49 1:02	1:03 1:18	1:19 1:36	1:37 1:55	1:56 2:17	2:18 2:42	2:43 3:10	3:11 3:45	3:46 4:29	4:30 5:27	5:28 6:56	6:57 10:05	10:00 12:00*
O	0:10 0:23	0:24 0:36	0:37 0:51	0:52 1:07	1:08 1:24	1:25 1:43	1:44 2:04	2:05 2:29	2:30 2:59	3:00 3:33	3:34 4:17	4:18 5:16	5:17 6:44	6:45 9:54	9:55 12:00*
	N	0:10 0:24	0:25 0:39	0:40 0:54	0:55 1:11	1:12 1:30	1:31 1:53	1:54 2:18	2:19 2:47	2:48 3:22	3:23 4:04	4:05 5:03	5:04 6:32	6:33 9:43	9:44 12:00*
		M	0:10 0:25	0:26 0:42	0:43 0:59	1:00 1:18	1:19 1:39	1:40 2:05	2:06 2:34	2:35 3:08	3:09 3:52	3:53 4:49	4:50 6:18	6:19 9:28	9:29 12:00*
			L	0:10 0:26	0:27 0:45	0:46 1:04	1:05 1:25	1:26 1:49	1:50 2:19	2:20 2:53	2:54 3:36	3:37 4:35	4:36 6:02	6:03 9:12	9:13 12:00*
				K	0:10 0:28	0:29 0:49	0:50 1:11	1:12 1:35	1:36 2:03	2:04 2:38	2:39 3:21	3:22 4:19	4:20 5:48	5:49 8:58	8:59 12:00*
					J	0:10 0:31	0:32 0:54	0:55 1:19	1:20 1:47	1:48 2:20	2:21 3:04	3:05 4:02	4:03 5:40	5:41 8:40	8:41 12:00*
						I	0:10 0:33	0:34 0:59	1:00 1:29	1:30 2:02	2:03 2:44	2:45 3:43	3:44 5:12	5:13 8:21	8:22 12:00*
							H	0:10 0:36	0:37 1:06	1:07 1:41	1:42 2:23	2:24 3:20	3:21 4:49	4:50 7:59	8:00 12:00*
								G	0:10 0:40	0:41 1:15	1:16 1:59	2:00 2:58	2:59 4:25	4:26 7:35	7:36 12:00*
									F	0:10 0:45	0:46 1:29	1:30 2:28	2:29 3:57	3:58 7:05	7:06 12:00*
										E	0:10 0:54	0:55 1:57	1:58 3:22	3:23 6:32	6:33 12:00*
											D	0:10 1:09	1:10 2:38	2:39 5:48	5:49 12:00*
												C	0:10 1:39	1:40 2:49	2:50 12:00*
													B	0:10 2:10	2:11 12:00*
														A	0:10 12:00*

Repetitive group at the beginning of the surface interval from previous dive

Instructions for Use

Surface interval time in the table is in *hours* and *minutes* (7:59 means 7 hours and 59 minutes). The surface interval must be at least 10 minutes.

Find the *repetitive group designation letter* (from the previous dive schedule) on the diagonal slope. Enter the table horizontally to select the surface interval time that is exactly between the actual surface interval times shown. The repetitive group designation for the *end* of the surface interval is at the head of the vertical column where the selected surface interval time is listed. For example, a previous dive was to 110 feet for 30 minutes. The diver remains on the surface 1 hour and 30 minutes and wishes to find the new repetitive group designation: The repetitive group from the last column of the 110/30 schedule in the Standard Air Decompression Tables is "J." Enter the surface interval credit table along the horizontal line labeled "J." The 1-hour-and-30-minute surface interval lies between the times 1:20 and 1:47. Therefore, the diver has lost sufficient inert gas to place him in group "G" (at the head of the vertical column selected).

*NOTE.—Dives following surface intervals of *more* than 12 hours are not considered repetitive dives. *Actual* bottom times in the Standard Air Decompression Tables may be used in computing decompression for such dives.

(FORMERLY TABLE 1-8, 1963 DIVING MANUAL)

TABLE 1-13.—*Repetitive dive timetable for air dives*

Repetitive groups	Repetitive dive depth (ft) (air dives)															
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
A	7	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2
B	17	13	11	9	8	7	7	6	6	6	5	5	4	4	4	4
C	25	21	17	15	13	11	10	10	9	8	7	7	6	6	6	6
D	37	29	24	20	18	16	14	13	12	11	10	9	9	8	8	8
E	49	38	30	26	23	20	18	16	15	13	12	12	11	10	10	10
F	61	47	36	31	28	24	22	20	18	16	15	14	13	13	12	11
G	73	56	44	37	32	29	26	24	21	19	18	17	16	15	14	13
H	87	66	52	43	38	33	30	27	25	22	20	19	18	17	16	15
I	101	76	61	50	43	38	34	31	28	25	23	22	20	19	18	17
J	116	87	70	57	48	43	38	34	32	28	26	24	23	22	20	19
K	138	99	79	64	54	47	43	38	35	31	29	27	26	24	22	21
L	161	111	88	72	61	53	48	42	39	35	32	30	28	26	25	24
M	187	124	97	80	68	58	52	47	43	38	35	32	31	29	27	26
N	213	142	107	87	73	64	57	51	46	40	38	35	33	31	29	28
O	241	160	117	96	80	70	62	55	50	44	40	38	36	34	31	30
Z	257	169	122	100	84	73	64	57	52	46	42	40	37	35	32	31

Instructions for Use

The bottom times listed in this table are called "residual nitrogen times" and are the times a diver is to consider he has *already* spent on bottom when he *starts* a repetitive dive to a specific depth. They are in minutes.

Enter the table horizontally with the repetitive group designation from the Surface Interval Credit Table. The time in each vertical column is the number of minutes that would be required (at the depth listed at the head of the column) to saturate to the particular group.

For example: The final group designation from the Surface Interval Credit Table, on the basis of a previous dive and surface interval, is "H." To plan a dive to 110 feet, determine the residual nitrogen time for this depth required by the repetitive group designation: Enter this table along the horizontal line labeled "H." The table shows that one must *start* a dive to 110 feet as though he had already been on the bottom for 27 minutes. This information can then be applied to the Standard Air Decompression Table or No-Decompression Table in a number of ways:

(1) Assuming a diver is going to finish a job and take whatever decompression is required, he must add 27 minutes to his actual bottom time and be prepared to take decompression according to the 110-foot schedules for the sum or equivalent single dive time.

(2) Assuming one wishes to make a quick inspection dive for the minimum decompression, he will decompress according to the 110/30 schedule for a dive of 3 minutes or less (27+3=30). For a dive of over 3 minutes but less than 13, he will decompress according to the 110/40 schedule (27+13=40).

(3) Assuming that one does not want to exceed the 110/50 schedule and the amount of decompression it requires, he will have to start ascent before 23 minutes of actual bottom time (50−27=23).

(4) Assuming that a diver has air for approximately 45 minutes bottom time and decompression stops, the possible dives can be computed: A dive of 13 minutes will require 23 minutes of decompression (110/40 schedule), for a total submerged time of 36 minutes. A dive of 13 to 23 minutes will require 34 minutes of decompression (110/50 schedule), for a total submerged time of 47 to 57 minutes. Therefore, to be safe, the diver will have to start ascent before 13 minutes or a standby air source will have to be provided.

(FORMERLY TABLE 1-9, 1963 DIVING MANUAL)

TABLE 1-14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)													Total ascent time (min:sec)
			130	120	110	100	90	80	70	60	50	40	30	20	10	
40	360	0:30													23	23:40
	480	0:30													41	41:40
	720	0:30													69	69:40
60	240	0:40												2	79	82:00
	360	0:40												20	119	140:00
	480	0:40												44	148	193:00
	720	0:40												78	187	266:00
80	180	1:00												35	85	121:20
	240	0:50											6	52	120	179:20
	360	0:50											29	90	160	280:20
	480	0:50											59	107	187	354:20
	720	0:40										17	108	142	187	455:20
100	180	1:00										1	29	53	118	202:40
	240	1:00										14	42	84	142	283:40
	360	0:50									2	42	73	111	187	416:40
	480	0:50									21	61	91	142	187	503:40
	720	0:50									55	106	122	142	187	613:40
120	120	1:20										10	19	47	98	176:00
	180	1:10									5	27	37	76	137	284:00
	240	1:10									23	35	60	97	179	396:00
	360	1:00								18	45	64	93	142	187	551:00
	480	0:50							3	41	64	93	122	142	187	654:00
	720	0:50							32	74	100	114	122	142	187	773:00
140	90	1:30									2	14	18	42	88	166:20
	120	1:30									12	14	36	56	120	240:20
	180	1:20								10	26	32	54	94	168	386:20
	240	1:10							8	28	34	50	78	124	187	511:20
	360	1:00						9	32	42	64	84	122	142	187	684:20
	480	1:00						31	44	59	100	114	122	142	187	801:20
	720	0:50					16	56	88	97	100	114	122	142	187	924:20
170	90	1:50								12	12	14	34	52	120	246:50
	120	1:30						2	10	12	18	32	42	82	156	356:50
	180	1:20					4	10	22	28	34	50	78	120	187	535:50
	240	1:20					18	24	30	42	50	70	116	142	187	681:50
	360	1:10				22	34	40	52	60	98	114	122	142	187	873:50
	480	1:00			14	40	42	56	91	97	100	114	122	142	187	1007:50
200	5	3:10													1	4:20
	10	3:00												1	4	8:20
	15	2:50											1	4	10	18:20
	20	2:50											3	7	27	40:20
	25	2:50											7	14	25	49:20
	30	2:40										2	9	22	37	73:20
	40	2:30									2	8	17	23	59	112:20
	50	2:30									6	16	22	39	75	161:20
	60	2:20								2	13	17	24	51	89	199:20
	90	1:50					1	10	10	12	12	30	38	74	134	324:20
	120	1:40				6	10	10	10	24	28	40	64	98	180	473:20
	180	1:20		1	10	10	18	24	24	42	48	70	106	142	187	685:20
	240	1:20		6	20	24	24	36	42	54	68	114	122	142	187	842:20
	360	1:10	12	22	36	40	44	56	82	98	100	114	122	142	187	1058:20

TABLE 1–14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet) 130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent time (min:sec)
210	5	3:20													1	4:30
	10	3:10												2	4	9:30
	15	3:00											1	5	13	22:30
	20	3:00											4	10	23	40:30
	25	2:50										2	7	17	27	56:30
	30	2:50										4	9	24	41	81:30
	40	2:40									4	9	19	26	63	124:30
	50	2:30								1	9	17	19	45	80	174:30
220	5	3:30													2	5:40
	10	3:20												2	5	10:40
	15	3:10											2	5	16	26:40
	20	3:00										1	3	11	24	42:40
	25	3:00										3	8	19	33	66:40
	30	2:50									1	7	10	23	47	91:40
	40	2:50									6	12	22	29	68	140:40
	50	2:40								3	12	17	18	51	86	190:40
230	5	3:40													2	5:50
	10	3:20											1	2	6	12:50
	15	3:20											3	6	18	30:50
	20	3:10										2	5	12	26	48:50
	25	3:10										4	8	22	37	74:50
	30	3:00									2	8	12	23	51	99:50
	40	2:50								1	7	15	22	34	74	156:50
	50	2:50								5	14	16	24	51	89	202:50
240	5	3:50													2	6:00
	10	3:30											1	3	6	14:00
	15	3:30											4	6	21	35:00
	20	3:20										3	6	15	25	53:00
	25	3:10									1	4	9	24	40	82:00
	30	3:10									4	8	15	22	56	109:00
	40	3:00								3	7	17	22	39	75	167:00
	50	2:50							1	8	15	16	29	51	94	218:00
250	5	3:50												1	2	7:10
	10	3:40											1	4	7	16:10
	15	3:30										1	4	7	22	38:10
	20	3:30										4	7	17	27	59:10
	25	3:20									2	7	10	24	45	92:10
	30	3:20									6	7	17	23	59	116:10
	40	3:10								5	9	17	19	45	79	178:10
	60	2:40					4	10	10	10	12	22	36	64	126	298:10
	90	2:10		8	10	10	10	10	10	28	28	44	68	98	186	514:10
260	5	4:00												1	2	7:20
	10	3:50											2	4	9	19:20
	15	3:40										2	4	10	22	42:20
	20	3:30									1	4	7	20	31	67:20
	25	3:30									3	8	11	23	50	99:20
	30	3:20								2	6	8	19	26	61	126:20
	40	3:10							1	6	11	16	19	49	84	190:20
270	5	4:10												1	3	8:30
	10	4:00											2	5	11	22:30
	15	3:50										3	4	11	24	46:30
	20	3:40									2	3	9	21	35	74:30

TABLE 1–14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)													Total ascent time (min:sec)
			130	120	110	100	90	80	70	60	50	40	30	20	10	
270—Con.	25	3:30	----	----	----	----	----	----	----	2	3	8	13	23	53	106:30
	30	3:30	----	----	----	----	----	----	----	3	6	12	22	27	64	138:30
	40	3:20	----	----	----	----	----	----	5	6	11	17	22	51	88	204:30
280	5	4:20	----	----	----	----	----	----	----	----	----	----	----	2	2	8:40
	10	4:00	----	----	----	----	----	----	----	----	----	1	2	5	13	25:40
	15	3:50	----	----	----	----	----	----	----	----	1	3	4	11	26	49:40
	20	3:50	----	----	----	----	----	----	----	----	3	4	8	23	39	81:40
	25	3:40	----	----	----	----	----	----	----	2	5	7	16	23	56	113:40
	30	3:30	----	----	----	----	----	----	1	3	7	13	22	30	70	150:40
	40	3:20	----	----	----	----	----	1	6	6	13	17	27	51	93	218:40
290	5	4:30	----	----	----	----	----	----	----	----	----	----	----	2	3	9:50
	10	4:10	----	----	----	----	----	----	----	----	----	1	3	5	16	29:50
	15	4:00	----	----	----	----	----	----	----	----	1	3	6	12	26	52:50
	20	4:00	----	----	----	----	----	----	----	----	3	7	9	23	43	89:50
	25	3:50	----	----	----	----	----	----	----	3	5	8	17	23	60	120:50
	30	3:40	----	----	----	----	----	----	1	5	6	16	22	36	72	162:50
	40	3:30	----	----	----	----	----	3	5	7	15	16	32	51	95	228:50
300	5	4:40	----	----	----	----	----	----	----	----	----	----	----	3	3	11:00
	10	4:20	----	----	----	----	----	----	----	----	----	1	3	6	17	32:00
	15	4:10	----	----	----	----	----	----	----	----	2	3	6	15	26	57:00
	20	4:00	----	----	----	----	----	----	----	2	3	7	10	23	47	97:00
	25	3:50	----	----	----	----	----	----	1	3	6	8	19	26	61	129:00
	30	3:50	----	----	----	----	----	----	2	5	7	17	22	39	75	172:00
	40	3:40	----	----	----	----	----	4	6	9	15	17	34	51	90	231:00
	60	3:00	----	4	10	10	10	10	10	14	28	32	50	90	187	460:00

TABLE 1-14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*—Continued

Extreme exposures—250 and 300 ft

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)																				Total ascent time (min:sec)
			200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	
250	120	1:50							5	10	10	10	10	16	24	24	36	48	64	94	142	187	684:10
	180	1:30					4	8	8	10	22	24	24	32	42	44	60	84	114	122	142	187	931:10
	240	1:30					9	14	21	22	22	40	40	42	56	76	98	100	114	122	142	187	1109:10
300	90	2:20					3	8	8	10	10	10	10	16	24	24	34	48	64	90	142	187	693:00
	120	2:00			4	8	8	8	8	10	14	24	24	24	34	42	58	66	102	122	142	187	890:00
	180	1:40	6	8	8	8	14	20	21	21	28	40	40	48	56	82	98	100	114	122	142	187	1168:00

Single Dives

(4) A *single dive* is the first dive of the day. It is denoted by an exposure to a specific depth in feet for a specific time in minutes. An example would be 134 feet for 14 minutes. The depth is the maximum depth attained. The time is the actual bottom time. Bottom time is the elapsed time between leaving the surface in descent and leaving the maximum depth in ascent. A combination of depth and time as listed in the decompression tables is called a dive schedule. All dives which are not separately listed are included and covered in the tables by the next deeper and next longer schedule. Do not interpolate.

Repetitive Dives

(5) Any dive performed within 12 hours of a previous dive is a *repetitive dive*. The period between dives is the *surface interval*. Decompression following a repetitive dive requires special consideration. This consideration is necessary because dissolved inert gas from the previous dive remains in the body at the *beginning* of the repetitive dive.

(6) A detailed consideration of all the factors involved in repetitive-dive decompression would be prohibitively complicated. The basic idea of this approach involves considering the previous dive, the surface interval, and the repetitive dive as a whole to yield an equivalent *single dive*. For the *depth* of the equivalent single dive, the *actual* depth of the repetitive dive is used. However, the *bottom time* is the sum of the actual time of the repetitive dive, plus an additional amount of time to account for the residual nitrogen from the previous dive and the surface interval.

(7) Upon surfacing from a dive, the diver is cataloged by table 1–10 or 1–11 into one of 16 lettered *repetitive groups* according to the amount of inert gas left in his body. During the surface interval the diver loses inert gas and is given credit for the loss by means of table 1–12, which shows the change from one group to another for various time intervals on the surface. For every depth of dive, there is a certain time of exposure which would bring the diver to the same degree of saturation as that represented by each repetitive group. This time, based on the residual inert gas from the previous dive and the surface interval, is called the *residual nitrogen time*. In table 1–13, residual nitrogen time is expressed as a number of minutes for various depths (in 10-foot increments) and for each repetitive group designation. The bottom time of the *equivalent single dive* is then obtained by adding this residual nitrogen time to the actual bottom time of the repetitive dive. The proper decompression for ascent from the repetitive dive may then be found in the Standard Air Decompression Table (table 1–10) by using the actual depth of the repetitive dive and the equivalent single-dive bottom time. Successive repetitive dives may be handled similarly.

U.S. Navy Standard Air Decompression Table

(8) The Standard Air Decompression Table (table 1–10) covers the normal range of diving. The depth limit is 190 feet. Stay within the limits of this table for all routine air dives.

(9) Details for the use of the Standard Air Decompression Tables are—

(*a*) The time of decompression stops listed in the table is in minutes.

(*b*) Enter the tables at the listed depth that is exactly equal to, or is the next greater than, the maximum depth attained during the dive.

(*c*) Select the bottom time of those listed for the selected depth that is exactly equal to or is next greater than the bottom time of the dive.

(*d*) Use the decompression stops listed on the line for the selected bottom time.

(*e*) For any repetitive diving, use the repetitive group designation listed on the same line (or if no decompression is required, obtain the repetitive group from table 1–11).

(*f*) Insure that the diver's *chest* is maintained as close as possible to each decompression depth for the number of minutes listed.

(*g*) The rate of ascent between stops is not critical for stops that are 50 feet or shallower. Delay in ascent from stops deeper than 50 feet could result in excess gas being absorbed.

(10) Specific examples of the use of the table are—

(*a*) A single dive is made to 82 feet for 36 minutes. To determine the proper decompression procedure: The next greater depth listed in the table is 90 feet. The next greater bottom time listed opposite 90 feet is 40 minutes. The proper decompression procedure is therefore a 7-minute stop at 10 feet in accordance with the 90/40 schedule.

(*b*) A single dive is made to 110 feet for 30 minutes. It is known that the depth did not exceed 110 feet. To determine the proper decompression procedure: The exact depth of 110 feet is listed. The exact time of 30 minutes is listed opposite 110 feet. Decompression is according to the 110/30 schedule unless the dive was particularly cold or arduous, or unless conditions prohibit accurate decompression. In any of these cases, the next deeper and longer schedule should be used, i.e., 120/40.

No-Decompression Table

(11) The No-Decompression Table is officially and more accurately titled *No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Schedules.* It is a new table which is required by repetitive diving. It is no longer sufficient merely to know the limits at which decompression requirements begin. In repetitive diving one must know the amount of nitrogen remaining in the tissues from any dive, no matter how short or shallow. The repetitive group designations provide that information.

(12) Repetitive group designations are given for depths of 10 feet to 40 feet in 5-foot increments, and for depths of 40 feet to 190 feet in 10-foot increments. Opposite each depth and each repetitive group is listed the maximum bottom time which will allow the diver to remain within the group. On the assumption that it is the operational limit, the times for 10 to 25 feet end at approximately 5 hours. From 40 feet on, the times end at the no-decompression limit.

(13) The no-decompression limits listed in this table for depths of 40 feet and greater are useful in planning operations. The diver may surface directly (no-decompression dive) as long as the bottom time is less than the maximum listed for the depth. For depths not greater than 33 feet, direct surfacing is permissible regardless of the bottom time.

(14) Other than the above uses to obtain no-decompression limits, the only purpose of this table is to provide the repetitive group designation for no-decompression dives. This knowledge is necessary to make repetitive dives after no-decompression dives.

(15) Details of the table and an example of the manner in which to obtain the repetitive group designations are given directly on the table.

Surface Interval Credit Table

(16) The Surface Interval Credit Table is another requirement of the repetitive diving system. It is the real reason for the success and efficiency of the repetitive dive system.

(17) The diver continues to lose nitrogen while he is on the surface until he is completely desaturated. This desaturation requires 12 hours or more. To provide efficient decompression instructions, it is necessary to know the amount of nitrogen remaining in the tissues at the time a repetitive dive commences. This table provides that information.

(18) The repetitive groups are the measuring units. In this table, the loss of inert gas with increasing length of surface interval is reflected in the change from one group to another.

(19) Details and an example of its use are given directly in the table.

Repetitive Dive Timetable

(20) The Repetitive Dive Timetable lists the number of minutes at each depth that will build up the nitrogen partial pressure represented by each repetitive group.

(21) For the diver's known repetitive group designation, the system gives an arbitrary bottom time (the residual nitrogen time) that the diver must assume he has already completed before he starts his repetitive dive. This arbitrary bottom time and the actual bottom time of the repetitive dive are added to yield the bottom time of the equivalent single dive mentioned previously.

(22) Details and an example of its use are given directly on the table.

(23) There is one exception to the table. It occasionally occurs when the repetitive dive is to the same depth as, or to a greater depth than, the initial dives, and when the surface interval is short. Because of the necessity to account for the greatest exposure within a group, the arbitrary bottom time assigned may be greater than the sum of the actual bottom times of the pre-

vious dives. In such a case (if the repetitive dive is to the same depth as or greater depth than the previous dive or dives), add the actual bottom time of the previous dives to the actual bottom time of the repetitive dive.

Decompression for Exceptional Exposures

(24) The U.S. Navy Standard Air Decompression Table for Exceptional Exposures (table 1–14) includes only schedules of decompression for exceptional or emergency cases. Schedules are provided for 120-minute exposures up to 140 feet, and for extreme exposures up to 300 feet. Great demands are imposed upon the diver's endurance by emergencies necessitating use of the table. Therefore, complete assurance of success of the decompression schedules is impossible.

(25) Repetitive group designations are not given in the Table for Exceptional Exposures. Never follow a dive covered by that table with a repetitive dive. Make every effort to limit the equivalent single dive schedule of repetitive dives to the Standard Air Decompression Tables. The diving officer must be the one to weigh the need for any dive in the Table for Exceptional Exposures against the increased danger and demands on the diver's physical endurance.

Repetitive Dive Worksheet

(26) Figure 1–31(*a*) is a suggested worksheet for the selection of decompression schedules in repetitive diving. A systematic approach of this kind must *always* be used when the repetitive diving tables are applied.

(27) The following example demonstrates the use of the worksheet (fig. 1–31(*b*)). A diver makes a dive to 105 feet with a bottom time of 24 minutes, and decompresses properly according to the Standard Air Decompression Table. After being on the surface for 2 hours, he is required to make a second dive, this time to 145 feet. It is anticipated that 15 minutes' bottom time will be required to complete his work. The problem is to determine the proper decompression for his second or *repetitive* dive. The time and depth of his first or *previous dive* are used in worksheet part I. Table 1–10 indicates that the diver is in repetitive group H (according to the 110/25 schedule). During the surface interval of 2 hours he loses sufficient nitrogen to change from group H to group E, according to the Surface Interval Credit Table (table 1–12). His residual nitrogen time may now be determined by referring to the Repetitive Dive Timetable (table 1–13), using the depth of his second or repetitive dive and the *new* group from the end of the surface interval. This table indicates that the diver's residual nitrogen time is 12 minutes. The 15-minute actual bottom time of the repetitive dive is added to the residual nitrogen time to obtain the *equivalent single dive time*, which is 27 minutes. This time is used, as indicated in worksheet part V, to select the decompression schedule for the repetitive dive; in this example, the 150/30 schedule from table 1–10.

More Than One Repetitive Dive

(28) When one repetitive dive is to be followed by another, the procedure for selecting the proper decompression schedule for the first repetitive dive is *repeated*. The time and depth of the equivalent single dive of the *first* repetitive dive calculation becomes the time and depth of the previous dive of the *second* repetitive dive calculation. That is, the time and depth used in worksheet part V (fig. 1–31(*b*)) become the time and depth in part I of the following worksheet.

1.5.3 MIXED-GAS DECOMPRESSION TABLES

Nitrogen-Oxygen Decompression Tables

(1) The fundamental principle of decompression from nitrogen-oxygen dives is that an *equivalent air depth* is established for the actual depth of the dive. This equivalent air depth is then combined with the actual bottom time of the dive to determine a schedule to use in the Standard Air Decompression Table.

(2) No credit is allowed for the fact that high-oxygen mixtures are breathed during decompression on the stops established for air decompression.

(3) Definitions of equivalent air depth and other details of nitrogen-oxygen diving are given in section 3.6.

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

___ minutes } see table 1-10 or 1-11 for } Group___
____ feet } repetitive group designation }

II. SURFACE INTERVAL:

__hours___minutes on surface } see table 1-12 } Group___
Group___ (from I.) } for new group }

III. RESIDUAL NITROGEN TIME:

____ feet (depth of repetitive dive) } see table } ___minutes
Group___ (from II.) } 1-13 }

IV. EQUIVALENT SINGLE DIVE TIME:

___ minutes (residual nitrogen time from III.)

(add) ___ minutes (actual bottom time of repetitive dive)

(sum) ___ minutes

V. DECOMPRESSION FOR REPETITIVE DIVE:

___ minutes (equivalent single dive time from IV.) } see table
____ feet (depth of repetitive dive) } 1-10 or 1-11

☐ No decompression required

or

Decompression stops: ____ feet ____ minutes
____ feet ____ minutes
____ feet ____ minutes
____ feet ____ minutes

FIGURE 1-31(*a*).—Repetitive dive worksheet.

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

24 minutes, 105 feet — see table 1-10 or 1-11 for repetitive group designation — Group H

II. SURFACE INTERVAL:

2 hours 0 minutes on surface, Group H (from I.) — see table 1-12 for new group — Group E

III. RESIDUAL NITROGEN TIME:

145 feet (depth of repetitive dive), Group E (from II.) — see table 1-13 — 12 minutes

IV. EQUIVALENT SINGLE DIVE TIME:

12 minutes (residual nitrogen time from III.)

(add) 15 minutes (actual bottom time of repetitive dive)

(sum) 27 minutes

V. DECOMPRESSION FOR REPETITIVE DIVE:

27 minutes (equivalent single dive time from IV.), 145 feet (depth of repetitive dive) — see table 1-10 or 1-11

☐ No decompression required

or

Decompression stops: 20 feet 8 minutes
10 feet 24 minutes
____ feet ____ minutes
____ feet ____ minutes

FIGURE 1-31(b).—Repetitive dive worksheet (filled in).

Tables

(4) Use the Equivalent Air Tables (table 1-15) to obtain the equivalent air depth with which to enter the Standard Air Decompression Table.

(5) To apply the tables, use the following procedure:

(*a*) Determine the actual diving depth.

(FORMERLY TABLE 1-10, 1963 DIVING MANUAL)

TABLE 1-15.—*Nitrogen-oxygen equivalent air depth table*

Supply oxygen 60 percent

Nonswimming dive flow setting 4 lpm	Swimming dive flow setting 7 lpm	Nonswimming dive flow setting 7 lpm	Equivalent air depth
Actual depth up to—	Actual depth up to—	Actual depth up to—	
51	55	55	30

Supply oxygen 40 percent

Nonswimming dive flow setting 8 lpm	Swimming dive flow setting 12 lpm	Nonswimming dive flow setting 12 lpm	Equivalent air depth
Actual depth up to—	Actual depth up to—	Actual depth up to—	
36	39	40	30
47	51	52	40
58	62	64	50
69	74	76	60
80	85	88	70
91	97	99	80

Supply oxygen 32.5 percent

Nonswimming dive flow setting 13 lpm	Swimming dive flow setting 21 lpm	Nonswimming dive flow setting 21 lpm	Equivalent air depth
Actual depth up to—	Actual depth up to—	Actual depth up to—	
33	35	36	30
44	46	47	40
54	57	58	50
65	68	69	60
75	79	80	70
86	89	91	80
96	100	102	90
107	111	113	100
117	122	123	110
128	130	130	120

(FORMERLY TABLE 1-10, 1963 DIVING MANUAL)

TABLE 1-15a.—*Nitrogen-oxygen equivalent air depth table for exceptional exposures*

Supply oxygen 60 percent

Nonswimming dive flow setting 4 lpm	Swimming dive flow setting 7 lpm	Nonswimming dive flow setting 7 lpm	Equivalent air depth
Actual depth up to—	Actual depth up to—	Actual depth up to—	
51	65	68	30
64	77	77	40
77			50

Supply oxygen 40 percent

Nonswimming dive flow setting 8 lpm	Swimming dive flow setting 12 lpm	Nonswimming dive flow setting 12 lpm	Equivalent air depth
Actual depth up to—	Actual depth up to—	Actual depth up to—	
36	39	40	30
47	51	52	40
58	62	64	50
69	74	76	60
80	85	88	70
91	97	99	80
102	108	111	90
113	120	123	100
124	131	132	110

Supply oxygen 32.5 percent

Nonswimming dive flow setting 13 lpm	Swimming dive flow setting 21 lpm	Nonswimming dive flow setting 21 lpm	Equivalent air depth
Actual depth up to—	Actual depth up to—	Actual depth up to—	
33	35	36	30
44	46	47	40
54	57	58	50
65	68	69	60
75	79	80	70
86	89	91	80
96	100	102	90
107	111	113	100
117	122	123	110
128	133	134	120
138	144	145	130
149	155	156	140
160	165	167	150
170	170	170	160

(*b*) Select the table corresponding to the mixture in use for the dive.

(*c*) Enter the column corresponding to the flow setting and diving work condition.

(*d*) Find the next greater value of actual depth tabulated.

(*e*) Read the corresponding equivalent air depth.

(*f*) Decompress according to the Standard Air Decompression Table for the equivalent air depth and the actual bottom time.

(*g*) The depth and time of the dive must be within the limits imposed by table 1–16 to avoid hazardous partial pressures of oxygen. The oxygen limits imposed by table 1–16*a* should never be exceeded unless it is absolutely necessary for exceptional operational requirements.

(FORMERLY TABLE 1-11, 1963 DIVING MANUAL)

TABLE 1–16.—*Oxygen partial pressure limits*

Exposure time (min)	Maximum oxygen partial pressure (atmospheres)
30	1. 6
40	1. 5
50	1. 4
60	1. 3
80	1. 2
120	1. 1
240	1. 0

(FORMERLY TABLE 1-11, 1963 DIVING MANUAL)

TABLE 1–16*a*.—*Oxygen partial pressure limits for exceptional exposures*

Exposure time (min)	Maximum oxygen partial pressure (atmospheres)
30	2. 0
40	1. 9
60	1. 8
80	1. 7
100	1. 6
120	1. 5
180	1. 4
240	1. 3

(6) Make repetitive dives in accordance with the instructions given. Use the equivalent air depth of a repetitive dive as the repetitive dive depth in the Repetitive Dive Timetable.

(7) The oxygen content of the breathing mixture at the maximum depth resulting from each supply gas mixture in table 1–15 permits no longer than a 30-minute exposure time at this depth in accordance with table 1–16. For example, a 60-percent oxygen in nitrogen supply mixture may be used for dives to 55 feet with an equivalent air depth of 30 feet. Though exposure time is not limited by decompression requirement, it is restricted to no longer than 30 minutes by the oxygen toxicity limits. The same exposure time limits apply to the maximum depth permitted for 40 percent and 32½ percent oxygen mixtures. Dives to less than the maximum depth for a given supply gas must also be in accordance with the time limits of table 1–16. Table 1–15*a* is an Exceptional Exposure Table in accordance with the oxygen partial pressure limits imposed by table 1–16*a* and should never be used except for reasons of absolute necessity.

(8) Nonswimming dive flow settings are required in ordnance disposal for brief exposures with minimal exertion in order that the volume of the exhaust can be reduced to avoid excessive sound production in the water. The decreased flow setting does not provide sufficient oxygen in the breathing mixture for dives with greater than minimal exertion.

Helium-Oxygen Decompression Tables

(9) The use of oxygen-enriched mixtures in semiclosed-circuit apparatus with a constant mass flow arrangement permits a considerable increase in diving time over open-circuit apparatus, primarily due to decreased gas utilization rates. There are several limiting factors that are markedly improved by using helium-oxygen mixtures instead of nitrogen-oxygen mixtures. The factors of oxygen toxicity and carbon dioxide retention are reduced and impairment of the diver's performance at depth due to narcosis is avoided.

(10) At the present time, two gas mixtures are permitted for use in this type of diving. The standard mixture is 68 percent helium, 32 percent oxygen, and all decompression schedules relate to this mixture which can be used to a maximum depth of 200 feet for 30 minutes. The second gas mixture is 60 percent helium, 40 percent oxygen and is limited to 80 feet of depth.

This latter mixture is intended mainly for use in depths of less than 50 feet because the lower flow rates required provide for longer mission times when required.

(11) The use of the apparatus to which these tables apply is described in section 3.6. When the 68 percent helium, 32 percent oxygen mixture is used, the injection flow rate as measured at the surface should be 18.5 lpm. However, using the present type of flowmeters which are calibrated for air, the reading of the flowmeter will be 12.5 lpm. When the 60 percent helium, 40 percent oxygen mixture is used, the surface flow rate should be 11 lpm, which will read 8 lpm on the air-calibrated flowmeter.

Tables

(12) The tables for *Helium-Oxygen Decompression for Mixed-Gas Scuba* are very similar in many ways to the *U.S. Navy Standard Air Decompression Tables.* Table 1–17 is self-explanatory. The rate of descent should not exceed 75 feet per minute. The rate of ascent should be 60 feet per minute from the bottom and between stops. Note that these tables allow for repetitive diving, and, therefore, there is a repetitive group designator for each schedule in the last column.

TABLE 1–17.—*Helium-oxygen decompression table for mixed-gas scuba using 68 to 32 percent helium-oxygen supply mixture*

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent time (min:sec)	Repetitive group
			50	40	30	20	10		
40	260						0	0:40	L
50	180						0	0:50	L
	200	0:40					20	20:50	L
60	130						0	1:00	L
	150	0:50					20	21:00	L
	170	0:50					35	36:00	L
70	85						0	1:10	J
	100	1:00					15	16:10	K
	115	1:00					25	26:10	L
	130	1:00					40	41:10	L
80	60						0	1:20	I
	70	1:00				5	10	16:20	J
	80	1:00				10	15	26:20	K
	90	1:00				10	25	36:20	K
	100	1:00				10	35	46:20	K
90	45						0	1:30	H
	60	1:10				5	10	16:30	J
	70	1:10				5	20	26:30	K
	85	1:10				10	30	41:30	L
100	35						0	1:40	G
	50	1:20				5	15	21:40	J
	60	1:20				10	20	31:40	K
	70	1:10			5	15	25	46:40	K
110	30						0	1:50	G
	40	1:30				5	10	16:50	H
	50	1:30				10	20	31:50	J
	65	1:20			5	15	25	46:50	L

TABLE 1-17.—*Helium-oxygen decompression table for mixed-gas scuba using 68 to 32 percent helium-oxygen supply mixture*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)					Total ascent time (min:sec)	Repetitive group
			50	40	30	20	10		
120	25	--------	--------	--------	--------	--------	0	2:00	G
	35	1:40	--------	--------	--------	5	10	17:00	I
	45	1:30	--------	--------	5	10	15	32:00	K
	55	1:30	--------	--------	10	15	20	47:00	L
130	20	--------	--------	--------	--------	--------	0	2:10	F
	30	1:50	--------	--------	--------	5	10	17:10	I
	40	1:40	--------	--------	5	10	15	32:10	J
	50	1:30	--------	5	5	15	20	47;10	L
140	15	--------	--------	--------	--------	--------	0	2:20	E
	25	2:00	--------	--------	--------	5	10	17:20	G
	35	1:50	--------	--------	5	10	20	37:20	J
	45	1:40	--------	5	5	15	25	52:20	K
150	15	--------	--------	--------	--------	--------	0	2:30	E
	20	2:10	--------	--------	--------	5	10	17:30	G
	30	2:00	--------	--------	5	10	15	32:30	J
	40	1:50	--------	5	10	15	20	52:30	K
160	10	--------	--------	--------	--------	--------	0	2:40	E
	20	2:10	--------	--------	5	5	10	22:40	G
	35	2:00	--------	5	10	10	20	47:40	K
170	10	--------	--------	--------	--------	--------	0	2:50	E
	20	2:20	--------	--------	5	5	10	22:50	H
	35	2:10	--------	5	10	15	20	52:50	K
180	5	--------	--------	--------	--------	--------	0	3:00	C
	10	2:40	--------	--------	--------	5	10	18:00	E
	20	2:20	--------	5	5	10	10	33:00	H
	30	2:20	--------	5	10	15	20	53:00	K
190	10	2:50	--------	--------	--------	5	10	18:10	E
	20	2:30	--------	5	5	10	20	43:10	H
	30	2:20	5	5	10	15	25	63:10	K
200	10	3:00	--------	--------	--------	5	15	23:20	F
	20	2:40	--------	5	5	10	20	43:20	I
	30	2:30	5	5	10	15	35	73:20	K

(13) Table 1–18 allows for oxygen decompression from helium-oxygen mixed-gas dives. This procedure permits a considerable saving in terms of the required decompression time as compared to table 1–17. The semiclosed-circuit apparatus presently in use in the U.S. Navy is not usually provided with the capability for oxygen decompression. However, by the addition of a separate oxygen cylinder and injection system it can be adapted for this kind of decompression. If this type of adaptation is used, the shift to oxygen is made at the first oxygen stop (20 or 30 feet) in these schedules. At the first oxygen stop, the oxygen apparatus is activated and the helium-oxygen mixture injection is secured. The breathing bags are then purged thoroughly three times. Table 1–18 allows 2 minutes to complete this procedure. The decompression time at the first oxygen stop does not start until after the required 2 minutes allowed for oxygen purging have elapsed. Oxygen decompression can also be accomplished even if the apparatus has not been adapted for this purpose. This can be done by supplying the diver with a surface-supplied source of oxygen which is delivered to a demand regulator at the required decompression depth. It should be noted that this procedure should only be used when the exact location of the diver is known, such as in operations using a descending line.

(14) Table 1–19 delineates the no-decompression limits and the subsequent repetitive group designations. It is similar to table 1–11 and is self-explanatory.

(15) Table 1–20 is similar to table 1–12 and provides the basis to determine the repetitive group at the end of a given surface interval. Note that the *minimum* surface interval is 30 minutes.

(16) Table 1–21 is similar to table 1–13 and is used in the same manner. The most obvious difference is that it deals with residual helium time rather than residual nitrogen time.

1.5.4 HELIUM-OXYGEN DECOMPRESSION TABLES

(1) The use of a helium-oxygen mixture as a breathing medium during exposure to pressure requires separate instructions and procedures for decompression. The helium-oxygen decompression tables which follow are different from those used for ordinary compressed air diving. The tables are complicated, but at this time further simplification is impracticable. Further important information about physiological aspects of helium-oxygen mixtures has previously been discussed. The special methods and equipment applicable are discussed in chapter 2 of this manual.

TABLE 1–18.—*Helium-oxygen decompression table for mixed-gas scuba using 68 to 32 percent supply mixture and oxygen decompression*

Depth (ft)	Time (min)	Decompression stops: He-O₂ 50′	He-O₂ 40′		Oxygen 30′	Oxygen 20′	Repetitive group
60	170			ALLOW 2 MINUTES TO COMPLETE BAG PURGE TO OXYGEN		20	L
70	115					15	L
	130					25	L
80	80					15	K
	90					20	K
	100					25	K
90	70					15	K
	85					25	L
100	50					15	J
	60					20	K
	70				5	20	K
110	50					15	J
	65				5	20	L
120	45				5	15	K
	55				10	20	L
130	40				5	15	J
	50		5		5	20	L
140	35				5	15	J
	45		5		5	20	K
150	30				5	15	J
	40		5		10	20	K
160	20				5	10	G
	35		5		10	20	K
170	20				5	10	H
	35		5		10	20	K
180	20		5		5	10	H
	30		5		10	20	K
190	20		5		5	15	H
	30	5	5		10	20	K
200	20		5		5	20	I
	30	5	5		10	25	K

TABLE 1–19.—*No-decompression limits and repetitive group designation table for no-decompression helium-oxygen dives*

Depth (ft)	No-decompression limits (min)	Repetitive groups (He-O_2 dives)											
		A	B	C	D	E	F	G	H	I	J	K	L
10		70	190	720									
20		25	60	95	145	215	335	720					
30		15	35	60	80	110	145	185	245	335	525	720	
40	260	10	25	40	55	70	90	110	140	165	200	245	260
50	180	10	20	30	40	55	70	85	100	120	140	160	180
60	130	5	15	25	35	45	55	65	75	90	105	120	130
70	85	5	10	20	30	35	45	55	65	75	85		
80	60	5	10	15	25	30	40	45	55	60			
90	45	5	10	15	20	25	35	40	45				
100	35	5	10	15	20	25	30	35					
110	30	5	9	12	15	20	25	30					
120	25	5	8	10	15	20	22	25					
130	20		5	10	15	17	20						
140	15		5	10	12	15							
150	15		5	10	12	15							
160	10		5	6	8	10							
170	10		5	6	8	10							
180	5			5									
190													
200													

Instructions for Use

I. No-Decompression Limits:

This column shows at various depths the allowable diving time in minutes which permits surfacing directly at 60 feet per minute with no decompression stops. Longer exposures require use of the helium-oxygen decompression table for mixed-gas scuba table 1–17.

II. Repetitive Group Designation Table:

The tabulated exposure times are in minutes. The times at the various depths in each vertical column are the maximum exposures during which the diver will remain within the group listed at the head of the column.

To find the repetitive group designation upon surfacing for dives involving exposures up to and including the No-Decompression Limit: enter the table on the ***exact or next greater depth*** than that to which exposed and select the listed exposure time ***exact or next greater*** than the actual exposure time. The repetitive group designation is indicated by the letter at the head of the vertical column where the selected exposure time is listed.

For example: A dive was to 42 feet for 45 minutes, entering the 50-foot depth line. Since it is greater than 42 feet, the table shows that since group "D" is left after 40 minutes of exposure and group "E" after 55 minutes, group "E" (at the head of the column where the 55-minute exposure is listed) is the proper selection. Exposure times for depths less than 40 feet are listed up to 12 hours though this is considered to be beyond field requirements for this table.

TABLE 1–20.—*Surface interval credit table for helium-oxygen decompression dives*

[Repetitive group at the end of the surface interval (He-O_2 dives)]

Repetitive group at the beginning of the surface interval from previous dive	L	K	J	I	H	G	F	E	D	C	B	A
L	0:00 0:30	0:31 0:40	0:41 0:50	0:51 1:20	1:21 1:40	1:41 2:00	2:01 2:30	2:31 3:10	3:11 4:00	4:01 5:10	5:11 7:10	7:11 12:00*
K		0:00 0:30	0:31 0:40	0:41 1:00	1:01 1:20	1:21 1:50	1:51 2:20	2:21 3:00	3:01 3:50	3:51 5:00	5:01 7:00	7:01 12:00*
J			0:00 0:30	0:31 0:40	0:41 1:00	1:01 1:30	1:31 2:00	2:01 2:40	2:41 3:30	3:31 4:40	4:41 6:40	6:41 12:00*
I				0:00 0:30	0:31 0:50	0:51 1:20	1:21 1:50	1:51 2:20	2:21 3:10	3:11 4:20	4:21 6:20	6:21 12:00*
H					0:00 0:30	0:31 0:50	0:51 1:30	1:31 2:00	2:01 2:50	2:51 4:00	4:01 6:00	6:01 12:00*
G						0:00 0:30	0:31 1:00	1:01 1:40	1:41 2:30	2:31 3:40	3:41 5:40	5:41 12:00*
F							0:00 0:35	0:36 1:10	1:11 2:00	2:01 3:10	3:11 5:10	5:11 12:00*
E								0:00 0:40	0:41 1:30	1:31 2:40	2:41 4:40	4:41 12:00*
D									0:00 0:50	0:51 2:00	2:01 4:00	4:01 12:00*
C										0:00 1:20	1:21 3:10	3:11 12:00*
B											0:00 2:00	2:01 12:00*
A												0:00 12:00*

Instructions for Use

Surface interval time in the table is in *hours* and *minutes* (1:30 means 1 hour and 30 minutes). The surface interval must be at least 30 minutes.

Find the *repetitive group designation letter* (from the previous dive schedule) on the diagonal slope. Enter the table horizontally to select the surface interval time that is exactly between the actual surface interval times shown. The repetitive group designation for the *end* of the surface interval is at the head of the vertical column where the selected surface interval time is listed. For example, a previous dive was to 110 feet for 30 minutes. The diver wishes to remain on the surface for 1 hour and 30 minutes and wants to find the new repetitive group designation. The repetitive group from the last column of the 110/30 schedule in the Helium-Oxygen Decompression Tables is "G." Enter the surface interval credit table along the horizontal line labeled "G." The 1 hour and 30 minute surface interval lies between the times 1:01 and 1:40. Therefore, the diver has lost sufficient inert gas to place him in group "E" (at the head of the vertical column selected).

*NOTE.—Dives following surface intervals of more than 12 hours are not considered repetitive dives. Actual bottom times in the Helium-Oxygen Decompression Tables may be used in computing decompression for such dives.

TABLE 1–21.—*Repetitive dive timetable for helium-oxygen dives*

Repetitive groups	Repetitive dive depth (ft) (He-O_2 dives)																
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
A	13	10	8	7	6	6	5	5	4	4	4	4	3	3	3	3	3
B	26	21	17	14	13	11	10	9	8	8	7	7	6	6	6	5	5
C	40	32	26	22	19	17	15	14	13	12	11	10	9	9	8	8	8
D	56	44	35	30	26	23	20	19	17	15	14	13	13	12	11	11	10
E	74	57	45	38	33	29	26	23	21	19	18	17	16	15	14	13	13
F	93	71	56	47	40	35	31	28	26	24	22	20	19	18	17	16	15
G	115	86	67	56	47	42	37	33	30	28	26	24	22	21	20	19	18
H	139	102	79	66	55	48	43	39	35	32	29	28	26	24	22	21	20
I	168	120	92	76	64	56	49	44	40	37	33	31	29	27	26	24	23
J	203	141	105	87	72	63	55	49	45	41	37	35	32	31	28	27	25
K	248	165	120	98	80	71	61	55	49	45	42	39	36	34	32	30	28
L	305	191	137	111	91	79	68	61	55	50	46	43	40	37	35	33	31

Instructions for Use

The bottom times listed in this table are called "residual helium times" and are the times a diver is to consider he has *already* spent on the bottom when he *starts* a repetitive dive to a specific depth. They are in minutes.

Enter the table horizontally with the repetitive group designation from the Surface Interval Credit Table. The time in each vertical column is the number of minutes that would be required (at the depth listed at the head of the column) to saturate to the particular group.

For example: The final group designation from the Surface Interval Credit Table on the basis of a previous dive and surface interval is "H." To plan a dive to 110 feet, determine the residual helium time for this depth required by the repetitive group designation. Enter this table along the horizontal line labeled "H." The table shows that one must *start* a dive to 110 feet as though he had already been at this depth for 39 minutes. This information can then be app ied to the Helium-Oxygen Decompression Table or No-Decompression Table in a number of ways:

(1) Assuming a diver is going to finish a job and take whatever decompression is required, he must add 39 minutes to his actual bottom time and be prepared to take decompression according to the 110-foot schedules for the sum or equivalent single dive time.

(2) Assuming the diver wishes to make a quick inspection dive for the minimum decompression, he will decompress according to the 110/50 schedule for a dive of 11 minutes or less (39+11=50).

(3) Assuming that a diver has sufficient mixed gas for approximately 40 minutes bottom time and decompression stops, the possible dive can be computed: A dive of 11 minutes will require 32 minutes of decompression (110/50 schedule), for a total submerged time of 43 minutes. Therefore to be safe, the diver will have to start ascent before 11 minutes or a standby mixed gas source will have to be provided.

(2) Helium-oxygen decompression tables differ from the air tables in the following major respects:

(*a*) The partial pressure of the inert gas at depth and not the depth of the dive determines the particular table to use.

(*b*) The rate of ascent from the bottom to the first stop varies, and the means to compute it are given in the particular decompression schedule used.

(*c*) Repetitive diving is not allowed with less than a 12-hour surface interval.

(3) The helium-oxygen decompression tables are comprised of:

(*a*) Partial Pressure Table (table 1–22).

(*b*) Helium-Oxygen Decompression Table (table 1–23).

(*c*) Helium-Oxygen Decompression Table for Exceptional Exposures (table 1–23*a*).

(*d*) Emergency Table (He-O_2) (table 1–24).

(*e*) Emergency Table (Air) (table 1–25).

Oxygen Limits in Helium-Oxygen Diving

(4) Because the risk of incurring oxygen toxicity increases with the time of exposure to high oxygen pressure, the maximum safe limit for the oxygen partial pressure in helium-oxygen diving decreases as the bottom time of the dive increases. Table 1–16 gives the limits (which are related to the bottom time) for maximum oxygen partial pressure, expressed as atmospheres, in diving with helium-oxygen mixtures. The maximum allowable oxygen percentage for a gas mixture in helium-oxygen diving depends on the permissible partial pressure of oxygen. It can be determined from the following formula on pages 138 and 139.

(FORMERLY TABLE 1-12, 1963 DIVING MANUAL)

TABLE 1-22.—*Table of helium-oxygen partial pressures—40 feet to 380 feet (enter this table—select partial pressures)*

Depth (feet)	Oxygen percent												
	15	16	17	19	21	23	25	30	35	40	45	50	55
40	64	63	63	61	60	58	57	(*)	(*)	(*)	(*)	(*)	(*)
50	73	72	71	69	68	66	64	60	56	(*)	(*)	(*)	(*)
60	81	80	80	78	76	74	72	67	63	58	54	(*)	(*)
70	90	89	88	86	84	82	80	75	70	64	59	54	(*)
80	99	98	97	94	92	90	88	82	76	71	65	59	54
90	108	106	105	103	100	98	95	89	83	77	71	64	
100	116	115	114	111	108	106	103	96	90	83	76		
110	125	123	122	119	116	113	111	103	96	89	82		
120	134	132	131	127	124	121	118	111	103	95			
130	142	141	139	136	133	129	126	118	110	102			
140	151	149	148	144	141	137	134	125	116				
150	160	158	156	152	149	145	141	132	123				
160	168	166	165	161	157	155	149	139					
170	177	175	173	169	165	161	157	147					
180	186	184	182	177	173	169	165	154					
190	195	192	190	186	181	177	172						
200	203	201	199	194	189	185	180						
210	212	209	207	202	197	192	188						
220	221	218	216	210	205	200	195						
230	229	227	224	219	214	203	203						
240	238	235	233	227	222	216							
250	247	244	241	235	230	224							
260	255	252	250	244	238								
270	264	261	258	252	246								
280	273	270	267	260	254								
290	282	278	275	269									
300	290	287	284	277									
310	299	295	292	285									
320	308	304	301										
330	316	313	309										
340	325	321	318										
350	334	330	326										
360	342	338											
370	351	347											
380	360	356											

The heavy line indicates the maximum depth on each oxygen percent mixture for a 30-min exposure at 1.6 atmospheres PO_2. Partial pressures above the heavy line are applicable to table 1–23 ($He-O_2$ decompression table). Partial pressures below the heavy line are applicable only to table 1–23*a* ($He-O_2$ decompression table for exceptional exposures).

*No-decompression to 100 percent oxygen

$$\text{Cutoff depth for oxygen} = \frac{52.8}{\text{Oxygen percent}} - 33$$

$$\frac{52.8}{D+33} \times 100 = \text{maximum oxygen percent}$$

$$\frac{(D+33) \times \text{oxygen percent}}{33} = \text{Effective atmospheres of oxygen}$$

$$PP = (D+33) \times 1.00 - (\text{Oxygen percent} - 0.02)$$

16 percent is considered the minimum oxygen percentage for surface breathing. The Partial Pressure Tables are not designed for shifting to lower percentages of oxygen during the dive. Therefore, those Partial Pressure Tables requiring a lower percent of oxygen are for emergency use only.

370–711 O—70——11

(FORMERLY TABLE 1-13, 1963 DIVING MANUAL)

TABLE 1-23.—*Helium-oxygen decompression table*

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (60)																	
10	4															0	4
20	4															0	4
30	4															0	4
40	4															0	4
60	4															0	4
80	2															6	8
100	2															7	9
120	2															9	11
140																	
160																	
180																	
200																	
240	2															13	15
PARTIAL PRESSURE (70)																	
10	3															6	9
20	3															7	10
30	3															9	12
40	3															10	13
60	3															15	18
80	3															17	20
100	3															22	25
120	3															25	28
140	3															27	30
160	3															29	32
180	3															31	34
200	3															31	34
220	3															33	36
240	3															33	36
PARTIAL PRESSURE (80)																	
10	3															6	9
20	3															10	13
30	3															13	16
40	3															17	20
60	3															24	27
80	3															32	35
100	3															40	43
120	3															42	45
140	3															45	48
160	3															47	50
180	3															48	51
200	3															48	51
220	3															48	51
240	3															50	53

TABLE 1-23.—*Helium-oxygen decompression table*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (90)																	
10	3															8	11
20	3															15	18
30	3															18	21
40	3															23	26
60	3															35	38
80	3															45	48
100	3															50	53
120	3															55	58
140	3															58	61
160	3															60	63
180	3															60	63
200	3															62	65
220	3															62	65
240	3															63	66
PARTIAL PRESSURE (100)																	
10	3															10	13
20	3															17	20
30	3															24	27
40	3															31	34
60	3															47	50
80	3															56	59
100	3															63	66
120	3															67	70
140	3															70	73
160	3															72	75
180	3															73	76
200	3															73	76
220	3															73	76
240	3															75	78
PARTIAL PRESSURE (110)																	
10	3															12	15
20	3															21	24
30	3															31	34
40	3															39	42
60	3															56	59
80	3															67	70
100	3															75	78
120	3															78	81
140	3															81	84
160	3															83	86
180	3															84	87
200	3															84	87
220	3															85	88
240	3															86	89

TABLE 1–23.—*Helium oxygen decompression table*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (120)																	
10	3															14	17
20	3															25	28
30	3															36	39
40	3															47	50
60	3															66	69
80	3															77	80
100	3															84	87
120	3															87	90
140	3															90	93
160	3															92	95
180	3															93	96
200	3															93	96
220	3															95	98
240	3															97	100
PARTIAL PRESSURE (130)																	
10	3														0	16	19
20	3														0	29	32
30	3														0	42	45
40	3														0	53	56
60	3														0	73	76
80	3														0	86	89
100	3														0	92	95
120	3														0	96	99
140	3														0	99	102
160	3														10	92	105
180	3														10	93	106
200	3														10	94	107
220	3														10	95	108
240	3														10	96	109
PARTIAL PRESSURE (140)																	
10	3														0	19	22
20	3														0	34	37
30	3														0	49	52
40	3														0	62	65
60	3														0	82	85
80	3														0	94	97
100	3														0	99	102
120	3														10	97	110
140	3														10	98	111
160	3														10	99	112
180	3														12	99	114
200	3														13	99	115
220	3														14	99	116
240	3														15	99	117

TABLE 1-23.—*Helium-oxygen decompression table*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (150)																	
10	3													0	10	11	24
20	3													0	10	28	41
30	3													0	10	45	58
40	3													7	10	59	79
60	3													7	10	78	98
80	3													7	10	90	110
100	3													7	10	96	116
120	3													7	11	98	119
140	3													7	13	99	122
160	3													8	15	99	125
180	3													9	15	99	126
200	3													10	16	99	128
220	3													11	16	99	129
240	3													12	16	99	130
PARTIAL PRESSURE (160)																	
10	3												0	0	10	12	25
20	3												0	7	10	33	53
30	3												0	7	10	50	70
40	3												0	7	10	65	85
60	3												0	7	10	84	104
80	3												0	7	10	96	116
100	3												0	7	13	99	122
120	3												0	9	16	99	127
140	3												0	15	16	99	133
160	3												0	18	16	99	136
180	3												0	20	16	99	138
200	3												0	22	16	99	140
220	3												0	23	16	99	141
240	3												7	19	16	99	144
PARTIAL PRESSURE (170)																	
10	3												0	7	10	15	35
20	3												0	7	10	36	56
30	3												0	7	10	55	75
40	3												0	7	10	70	90
60	3												7	6	10	83	109
80	3												7	9	10	98	127
100	3												7	13	14	98	135
120	3												7	17	16	99	142
140	3												8	21	16	99	147
160	3												11	22	16	99	151
180	3												11	23	16	99	152
200	3												12	23	16	99	153
220	3												14	23	16	99	155
240	3												16	23	16	99	157

TABLE 1-23.—*Helium-oxygen decompression table*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (180)																	
10	3											0	7	0	10	17	37
20	3											0	7	0	10	41	61
30	3											0	7	1	10	62	83
40	3											0	7	4	10	77	101
60	3											0	7	10	10	92	122
80	3											0	9	14	13	98	137
100	3											7	5	18	15	99	147
120	3											7	9	21	16	99	155
140	3											7	11	22	16	99	158
160	3											7	15	23	16	99	163
180	3											7	17	23	16	99	165
200	3											7	19	23	16	99	167
220	3											7	21	23	16	99	169
240	3											7	23	23	16	99	171
PARTIAL PRESSURE (190)																	
10	4											0	7	0	10	20	41
20	4											0	7	0	10	44	65
30	4											0	7	4	10	67	92
40	4											7	0	8	10	81	110
60	4											7	5	11	10	96	133
80	4											7	9	15	15	99	149
100	4											7	13	19	16	99	158
120	4											7	17	23	16	99	166
140																	
160																	
180																	
200																	
240																	
PARTIAL PRESSURE (200)																	
10	4										0	0	7	0	10	22	43
20	4										0	7	0	2	10	50	73
30	4										0	7	0	7	10	69	97
40	4										0	7	4	9	10	84	118
60	4										0	7	9	13	12	93	138
80	4										7	3	13	18	15	99	159
100	4										7	6	16	21	16	99	169
120	4										7	8	20	23	16	99	177
140																	
160																	
180																	
200																	
240																	

TABLE 1-23.—*Helium-oxygen decompression table*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (210)																	
10	4										0	7	0	0	10	25	46
20	4										0	7	0	4	10	53	78
30	4										7	0	3	7	10	74	105
40	4										7	0	7	10	10	86	124
60	4										7	4	10	14	13	98	150
80	4										7	8	14	18	16	99	166
100																	
120																	
140																	
160																	
180																	
200																	
240																	
PARTIAL PRESSURE (220)																	
10	4									0	0	7	0	0	10	28	49
20	4									0	7	0	1	6	10	57	85
30	4									0	7	0	6	7	10	79	113
40	4									0	7	3	9	10	10	90	133
60	4									7	0	9	11	17	13	98	159
80	4									7	3	11	15	20	13	99	172
100																	
120																	
140																	
160																	
180																	
200																	
240																	
PARTIAL PRESSURE (230)																	
10	4									0	0	7	0	2	10	30	53
20	4									0	7	0	3	7	10	61	92
30	4									0	7	2	6	9	10	81	119
40	4									7	0	6	9	11	10	93	140
60	4									7	4	9	12	18	14	99	167
80																	
100																	
120																	
140																	
160																	
180																	
200																	
240																	

TABLE 1-23.—*Helium-oxygen decompression table*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (240)																	
10	4								0	0	7	0	0	3	10	33	57
20	4								0	7	0	1	4	7	10	65	98
30	4								0	7	0	5	7	10	10	85	128
40	4								7	0	3	7	9	13	11	95	149
60	4								7	0	8	10	14	18	15	99	175
80																	
100																	
120																	
140																	
160																	
180																	
200																	
240																	
PARTIAL PRESSURE (250)																	
10	4								0	7	0	0	2	4	10	35	62
20	4								0	7	0	2	5	7	10	68	103
30	4								7	0	2	6	7	10	10	87	133
40	4								7	0	5	8	9	14	12	96	155
60																	
80																	
100																	
120																	
140																	
160																	
180																	
200																	
240																	
PARTIAL PRESSURE (260)																	
10	4								0	7	0	0	2	4	10	37	64
20	4								7	0	0	3	7	7	10	70	108
30	4								7	0	4	6	8	10	10	89	138
40	4								7	2	5	9	9	14	13	96	159
60																	
80																	
100																	
120																	
140																	
160																	
180																	
200																	
240																	

TABLE 1-23.—*Helium-oxygen decompression table*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (270)																	
10	4							0	7	0	0	0	4	4	10	40	69
20	4							0	7	0	2	4	6	7	10	74	114
30	4							7	0	2	5	6	9	10	10	92	145
40	4							7	0	3	8	9	10	15	14	96	166
60																	
80																	
100																	
120																	
140																	
160																	
180																	
200																	
240																	
PARTIAL PRESSURE (280)																	
10	4							0	7	0	0	2	3	4	10	42	72
20	4							7	0	0	2	6	6	8	10	78	121
30	4							7	0	3	6	6	9	13	10	93	151
40																	
60																	
80																	
100																	
120																	
140																	
160																	
180																	
200																	
240																	
PARTIAL PRESSURE (290)																	
10	4						0	0	7	0	0	3	3	4	10	46	77
20	4						0	7	0	0	4	6	7	7	10	81	126
30	4						7	0	1	5	5	9	9	12	10	96	158
40																	
60																	
80																	
100																	
120																	
140																	
160																	
180																	
200																	
240																	

(FORMERLY TABLE 1-13, 1963 DIVING MANUAL)

TABLE 1-23a.—*Helium-oxygen decompression table for exceptional exposures*

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (190)																	
10																	
20																	
30																	
40																	
60																	
80																	
100																	
120																	
140	4											9	19	23	16	99	170
160	4											11	20	23	16	99	173
180	4											13	21	23	16	99	176
200	4											14	22	23	16	99	178
220	4											15	23	23	16	99	180
240	4											17	23	23	16	99	182
PARTIAL PRESSURE (200)																	
10																	
20																	
30																	
40																	
60																	
80																	
100																	
120																	
140	4										7	11	21	23	16	99	181
160	4										7	15	23	23	16	99	187
180	4										7	17	23	23	16	99	189
200	4										7	18	23	23	16	99	190
220	4										7	20	23	23	16	99	192
240	4										8	20	23	23	16	99	193
PARTIAL PRESSURE (210)																	
10																	
20																	
30																	
40																	
60																	
80																	
100	4										7	12	17	23	16	99	178
120	4										8	15	21	23	16	99	186
140	4										10	17	21	23	16	99	190
160	4										12	17	22	23	16	99	193
180	4										14	18	22	23	16	99	196
200	4										16	18	23	23	16	99	199
220	4										17	19	23	23	16	99	201
240	4										18	20	23	23	16	99	203

TABLE 1–23*a*.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (220)																	
10																	
20																	
30																	
40																	
60																	
80																	
100	4									7	6	14	19	23	16	99	188
120	4									7	8	18	23	23	16	99	198
140	4									7	11	18	23	23	16	99	201
160	4									7	14	19	23	23	16	99	205
180	4									7	15	20	23	23	16	99	207
200	4									7	16	20	23	23	16	99	208
220	4									8	17	20	23	23	16	99	210
240	4									9	19	20	23	23	16	99	213
PARTIAL PRESSURE (230)																	
10																	
20																	
30																	
40																	
60																	
80	4								0	7	8	12	17	21	16	99	184
100	4								0	7	12	15	20	23	16	99	196
120	4								0	8	14	19	23	23	16	99	206
140	4								0	10	16	20	23	23	16	99	211
160	4								7	6	18	20	23	23	16	99	216
180	4								7	7	19	20	23	23	16	99	218
200	4								7	9	19	20	23	23	16	99	220
220	4								7	11	19	20	23	23	16	99	222
240	4								7	13	19	20	23	23	16	99	224
PARTIAL PRESSURE (240)																	
10																	
20																	
30																	
40																	
60																	
80	4								7	3	10	14	18	23	16	99	194
100	4								7	6	12	17	23	23	16	99	207
120	4								7	7	16	19	23	23	16	99	214
140	4								7	11	16	20	23	23	16	99	219
160	4								7	13	19	20	23	23	16	99	224
180	4								8	15	19	20	23	23	16	99	227
200	4								8	17	19	20	23	23	16	99	229
220	4								9	17	19	20	23	23	16	99	230
240	4								11	17	19	20	23	23	16	99	232

TABLE 1-23a.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (250)																	
10																	
20																	
30																	
40																	
60	4							0	7	4	8	11	14	19	16	99	182
80	4							0	7	7	11	16	18	23	16	99	201
100	4							0	7	10	14	19	23	23	16	99	215
120	4							7	3	12	17	19	23	23	16	99	223
140	4							7	4	15	18	19	23	23	16	99	228
160	4							7	7	16	19	19	23	23	16	99	233
180	4							7	9	17	19	20	23	23	16	99	237
200	4							7	11	17	19	20	23	23	16	99	239
220	4							7	12	17	19	20	23	23	16	99	240
240	4							7	13	17	19	20	23	23	16	99	241
PARTIAL PRESSURE (260)																	
10																	
20																	
30																	
40																	
60	4							7	0	7	9	12	16	21	16	99	191
80	4							7	3	9	13	15	21	23	16	99	210
100	4							7	6	11	14	19	23	23	16	99	222
120	4							7	8	13	19	20	23	23	16	99	232
140	4							7	11	15	19	20	23	23	16	99	237
160	4							8	13	17	19	20	23	23	16	99	242
180	4							9	14	17	19	20	23	23	16	99	244
200	4							10	16	17	19	20	23	23	16	99	247
220	4							11	16	17	19	20	23	23	16	99	248
240	4							13	16	17	19	20	23	23	16	99	250
PARTIAL PRESSURE (270)																	
10																	
20																	
30																	
40																	
60	4						0	7	3	7	10	14	16	21	16	99	197
80	4						0	7	6	10	13	17	23	23	16	99	218
100	4						7	2	9	13	16	20	23	23	16	99	232
120	4						7	4	11	14	19	20	23	23	16	99	240
140	4						7	5	14	15	19	20	23	23	16	99	245
160	4						7	7	15	17	19	20	23	23	16	99	250
180	4						7	9	16	17	19	20	23	23	16	99	253
200	4						7	11	16	17	19	20	23	23	16	99	255
220	4						7	13	16	17	19	20	23	23	16	99	257
240	4						7	15	16	17	19	20	23	23	16	99	259

TABLE 1–23a.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (280)																	
10																	
20																	
30																	
40	4						7	0	2	5	8	8	12	16	13	98	173
60	4						7	0	6	8	10	14	19	23	16	99	206
80	4						7	3	8	11	14	17	23	23	16	99	225
100	4						7	5	11	13	16	20	23	23	16	99	237
120	4						7	8	12	16	19	20	23	23	16	99	247
140	4						7	10	16	17	19	20	23	23	16	99	254
160	4						8	13	16	17	19	20	23	23	16	99	258
180	4						9	14	16	17	19	20	23	23	16	99	260
200	4						10	15	16	17	19	20	23	23	16	99	262
220	4						12	15	16	17	19	20	23	23	16	99	254
240	4						14	15	16	17	19	20	23	23	16	99	266
PARTIAL PRESSURE (290)																	
10																	
20																	
30																	
40	4					0	7	0	4	6	8	9	12	17	15	98	180
60	4					0	7	4	6	8	12	15	18	23	16	99	212
80	4					7	0	7	9	11	15	17	23	23	16	99	231
100	4					7	2	9	11	15	17	20	23	23	16	99	246
120	4					7	4	11	13	16	19	20	23	23	16	99	255
140	4					7	5	13	16	17	19	20	23	23	16	99	262
160	4					7	8	14	16	17	19	20	23	23	16	99	266
180	4					7	10	15	16	17	19	20	23	23	16	99	269
200	4					7	12	15	16	17	19	20	23	23	16	99	271
220	4					7	13	15	16	17	19	20	23	23	16	99	272
240	4					7	14	15	16	17	19	20	23	23	16	99	273
PARTIAL PRESSURE (300)																	
10	5				0	0	0	7	0	0	0	4	3	4	10	49	82
20	5				0	0	7	0	0	2	6	6	6	9	10	83	134
30	5				0	0	7	0	2	5	5	9	9	14	12	94	162
40	5				0	0	7	0	5	7	8	11	13	17	15	98	186
60	5				0	7	0	6	7	9	12	15	20	23	16	99	219
80	5				0	7	2	8	10	12	16	19	23	23	16	99	240
100	5				0	7	5	10	12	15	19	20	23	23	16	99	254
120	5				0	7	8	11	16	17	19	20	23	23	16	99	264
140	5				0	8	9	14	16	17	19	20	23	23	16	99	269
160	5				0	8	13	15	16	17	19	20	23	23	16	99	274
180	5				7	3	13	15	16	17	19	20	23	23	16	99	276
200	5				7	5	14	15	16	17	19	20	23	23	16	99	279
220	5				7	6	14	15	16	17	19	20	23	23	16	99	280
240	5				7	9	14	15	16	17	19	20	23	23	16	99	283

TABLE 1–23*a*.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (250)																	
10																	
20																	
30																	
40																	
60	4							0	7	4	8	11	14	19	16	99	182
80	4							0	7	7	11	16	18	23	16	99	201
100	4							0	7	10	14	19	23	23	16	99	215
120	4							7	3	12	17	19	23	23	16	99	223
140	4							7	4	15	18	19	23	23	16	99	228
160	4							7	7	16	19	19	23	23	16	99	233
180	4							7	9	17	19	20	23	23	16	99	237
200	4							7	11	17	19	20	23	23	16	99	239
220	4							7	12	17	19	20	23	23	16	99	240
240	4							7	13	17	19	20	23	23	16	99	241
PARTIAL PRESSURE (260)																	
10																	
20																	
30																	
40																	
60	4							7	0	7	9	12	16	21	16	99	191
80	4							7	3	9	13	15	21	23	16	99	210
100	4							7	6	11	14	19	23	23	16	99	222
120	4							7	8	13	19	20	23	23	16	99	232
140	4							7	11	15	19	20	23	23	16	99	237
160	4							8	13	17	19	20	23	23	16	99	242
180	4							9	14	17	19	20	23	23	16	99	244
200	4							10	16	17	19	20	23	23	16	99	247
220	4							11	16	17	19	20	23	23	16	99	248
240	4							13	16	17	19	20	23	23	16	99	250
PARTIAL PRESSURE (270)																	
10																	
20																	
30																	
40																	
60	4						0	7	3	7	10	14	16	21	16	99	197
80	4						0	7	6	10	13	17	23	23	16	99	218
100	4						7	2	9	13	16	20	23	23	16	99	232
120	4						7	4	11	14	19	20	23	23	16	99	240
140	4						7	5	14	15	19	20	23	23	16	99	245
160	4						7	7	15	17	19	20	23	23	16	99	250
180	4						7	9	16	17	19	20	23	23	16	99	253
200	4						7	11	16	17	19	20	23	23	16	99	255
220	4						7	13	16	17	19	20	23	23	16	99	257
240	4						7	15	16	17	19	20	23	23	16	99	259

TABLE 1–23*a*.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (280)																	
10	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
20	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
30	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
40	4	------	------	------	------	------	7	0	2	5	8	8	12	16	13	98	173
60	4	------	------	------	------	------	7	0	6	8	10	14	19	23	16	99	206
80	4	------	------	------	------	------	7	3	8	11	14	17	23	23	16	99	225
100	4	------	------	------	------	------	7	5	11	13	16	20	23	23	16	99	237
120	4	------	------	------	------	------	7	8	12	16	19	20	23	23	16	99	247
140	4	------	------	------	------	------	7	10	16	17	19	20	23	23	16	99	254
160	4	------	------	------	------	------	8	13	16	17	19	20	23	23	16	99	258
180	4	------	------	------	------	------	9	14	16	17	19	20	23	23	16	99	260
200	4	------	------	------	------	------	10	15	16	17	19	20	23	23	16	99	262
220	4	------	------	------	------	------	12	15	16	17	19	20	23	23	16	99	264
240	4	------	------	------	------	------	14	15	16	17	19	20	23	23	16	99	266
PARTIAL PRESSURE (290)																	
10	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
20	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
30	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
40	4	------	------	------	------	0	7	0	4	6	8	9	12	17	15	98	180
60	4	------	------	------	------	0	7	4	6	8	12	15	18	23	16	99	212
80	4	------	------	------	------	7	0	7	9	11	15	17	23	23	16	99	231
100	4	------	------	------	------	7	2	9	11	15	17	20	23	23	16	99	246
120	4	------	------	------	------	7	4	11	13	16	19	20	23	23	16	99	255
140	4	------	------	------	------	7	5	13	16	17	19	20	23	23	16	99	262
160	4	------	------	------	------	7	8	14	16	17	19	20	23	23	16	99	266
180	4	------	------	------	------	7	10	15	16	17	19	20	23	23	16	99	269
200	4	------	------	------	------	7	12	15	16	17	19	20	23	23	16	99	271
220	4	------	------	------	------	7	13	15	16	17	19	20	23	23	16	99	272
240	4	------	------	------	------	7	14	15	16	17	19	20	23	23	16	99	273
PARTIAL PRESSURE (300)																	
10	5	------	------	------	0	0	0	7	0	0	0	4	3	4	10	49	82
20	5	------	------	------	0	0	7	0	0	2	6	6	6	9	10	83	134
30	5	------	------	------	0	0	7	0	2	5	5	9	9	14	12	94	162
40	5	------	------	------	0	0	7	0	5	7	8	11	13	17	15	98	186
60	5	------	------	------	0	7	0	6	7	9	12	15	20	23	16	99	219
80	5	------	------	------	0	7	2	8	10	12	16	19	23	23	16	99	240
100	5	------	------	------	0	7	5	10	12	15	19	20	23	23	16	99	254
120	5	------	------	------	0	7	8	11	16	17	19	20	23	23	16	99	264
140	5	------	------	------	0	8	9	14	16	17	19	20	23	23	16	99	269
160	5	------	------	------	0	8	13	15	16	17	19	20	23	23	16	99	274
180	5	------	------	------	7	3	13	15	16	17	19	20	23	23	16	99	276
200	5	------	------	------	7	5	14	15	16	17	19	20	23	23	16	99	279
220	5	------	------	------	7	6	14	15	16	17	19	20	23	23	16	99	280
240	5	------	------	------	7	9	14	15	16	17	19	20	23	23	16	99	283

TABLE 1–23*a*.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes: 180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	Total time
PARTIAL PRESSURE (310)																	
10	5	------	------	------	0	0	0	7	0	0	2	3	3	5	10	52	87
20	5	------	------	------	0	0	7	0	0	4	5	6	6	11	10	84	138
30	5	------	------	------	0	7	0	0	5	5	7	8	9	14	12	96	168
40	5	------	------	------	0	7	0	3	5	8	8	11	13	18	15	99	192
60	5	------	------	------	0	7	3	6	7	10	12	18	22	23	16	99	228
80	5	------	------	------	7	0	6	9	11	12	16	19	23	23	16	99	246
100	5	------	------	------	7	1	9	10	14	17	19	20	23	23	16	99	263
120	5	------	------	------	7	4	11	12	14	17	19	20	23	23	16	99	270
140	5	------	------	------	7	5	12	15	16	17	19	20	23	23	16	99	277
160	5	------	------	------	7	8	14	15	16	17	19	20	23	23	16	99	282
180	5	------	------	------	7	10	14	15	16	17	19	20	23	23	16	99	284
200	5	------	------	------	7	12	14	15	16	17	19	20	23	23	16	99	286
220	5	------	------	------	8	13	14	15	16	17	19	20	23	23	16	99	288
240	5	------	------	------	9	13	14	15	16	17	19	20	23	23	16	99	289
PARTIAL PRESSURE (320)																	
10	5	------	------	0	0	0	7	0	0	0	3	3	3	7	10	54	92
20	5	------	------	0	0	7	0	0	2	4	5	6	7	10	10	85	141
30	5	------	------	0	0	7	0	2	4	5	7	8	11	15	13	98	175
40	5	------	------	0	7	0	1	4	6	7	8	12	15	19	16	99	199
60	5	------	------	0	7	0	5	6	9	11	13	17	20	23	16	99	231
80	5	------	------	0	7	3	7	9	11	13	17	20	23	23	16	99	253
100	5	------	------	0	7	5	9	11	13	17	19	20	23	23	16	99	267
120	5	------	------	0	7	7	12	13	16	17	19	20	23	23	16	99	277
140	5	------	------	7	2	9	12	15	16	17	19	20	23	23	16	99	283
160	5	------	------	7	3	11	14	15	16	17	19	20	23	23	16	99	288
180	5	------	------	7	5	11	14	15	16	17	19	20	23	23	16	99	290
200	5	------	------	7	6	13	14	15	16	17	19	20	23	23	16	99	293
220	5	------	------	7	7	13	14	15	16	17	19	20	23	23	16	99	294
240	5	------	------	7	9	13	14	15	16	17	19	20	23	23	16	99	296
PARTIAL PRESSURE (330)																	
10	5	------	------	0	0	0	7	0	0	0	4	3	3	7	10	56	95
20	5	------	------	0	0	7	0	0	3	5	5	6	8	10	10	88	147
30	5	------	------	0	7	0	0	4	4	6	7	9	11	17	13	98	181
40	5	------	------	0	7	0	4	4	6	7	9	12	16	20	16	99	205
60	5	------	------	7	0	2	6	8	9	11	14	17	23	23	16	99	240
80	5	------	------	7	0	6	8	8	13	14	19	20	23	23	16	99	261
100	5	------	------	7	2	7	10	13	16	17	19	20	23	23	16	99	277
120	5	------	------	7	4	9	12	13	16	17	19	20	23	23	16	99	283
140	5	------	------	7	6	11	13	15	16	17	19	20	23	23	16	99	290
160	5	------	------	7	8	13	14	15	16	17	19	20	23	23	16	99	295
180	5	------	------	7	10	13	14	15	16	17	19	20	23	23	16	99	297
200	5	------	------	7	12	13	14	15	16	17	19	20	23	23	16	99	299
220	5	------	------	9	12	13	14	15	16	17	19	20	23	23	16	99	301
240	5	------	------	10	12	13	13	15	16	17	19	20	23	23	16	99	302

TABLE 1–23*a*.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (340)																	
10	5	------	0	0	0	7	0	0	0	2	3	3	4	7	10	59	100
20	5	------	0	0	7	0	0	2	3	4	6	5	10	10	10	90	152
30	5	------	0	0	7	0	1	4	5	6	8	8	13	17	14	98	186
40	5	------	0	7	0	1	4	5	7	7	10	12	17	22	16	99	212
60	5	------	0	7	0	5	6	8	9	11	15	20	23	23	16	99	247
80	5	------	0	7	2	7	8	10	13	15	19	20	23	23	16	99	267
100	5	------	0	7	5	9	9	13	16	17	19	20	23	23	16	99	281
120	5	------	7	1	7	10	13	15	16	17	19	20	23	23	16	99	291
140	5	------	7	2	9	12	14	15	16	17	19	20	23	23	16	99	297
160	5	------	7	4	10	13	14	15	16	17	19	20	23	23	16	99	301
180	5	------	7	5	12	13	14	15	16	17	19	20	23	23	16	99	304
200	5	------	7	6	12	13	14	15	16	17	19	20	23	23	16	99	305
220	5	------	7	8	12	13	14	15	16	17	19	20	23	23	16	99	307
240	5	------	7	10	12	13	14	15	16	17	19	20	23	23	16	99	309
PARTIAL PRESSURE (350)																	
10	5	------	0	0	0	7	0	0	0	3	3	3	4	7	10	61	103
20	5	------	0	0	7	0	0	2	4	5	7	8	9	10	10	90	157
30	5	------	0	7	0	0	3	5	5	6	8	9	13	18	14	98	191
40	5	------	0	7	0	2	4	6	7	8	10	13	16	22	16	99	215
60	5	------	7	0	3	5	6	9	10	13	16	18	21	23	16	99	251
80	5	------	7	0	7	7	8	11	13	15	19	20	23	23	16	99	273
100	5	------	7	2	8	8	12	13	16	17	19	20	23	23	16	99	288
120	5	------	7	4	9	11	13	15	16	17	19	20	23	23	16	99	297
140	5	------	7	6	11	13	14	15	16	17	19	20	23	23	16	99	304
160	5	------	7	9	11	13	14	15	16	17	19	20	23	23	16	99	307
180	5	------	8	9	12	13	14	15	16	17	19	20	23	23	16	99	309
200	5	------	8	11	12	13	14	15	16	17	19	20	23	23	16	99	311
220	5	------	10	11	12	13	14	15	16	17	19	20	23	23	16	99	313
240	5	------	11	11	12	13	14	15	16	17	19	20	23	23	16	99	314
PARTIAL PRESSURE (360)																	
10	5	0	0	0	7	0	0	0	2	2	3	3	5	7	10	64	108
20	5	0	0	7	0	0	0	4	4	5	5	7	9	13	10	94	163
30	5	0	0	7	0	1	4	4	5	7	8	11	13	18	14	99	196
40	5	0	7	0	1	3	5	6	7	8	11	14	17	23	16	99	222
60	5	0	7	0	5	5	8	8	11	12	16	19	23	23	16	99	257
80	5	0	7	2	7	7	10	11	13	17	19	20	23	23	16	99	279
100	5	7	0	6	8	9	11	15	16	17	19	20	23	23	16	99	294
120	5	7	1	7	9	12	14	15	16	17	19	20	23	23	16	99	303
140	5	7	3	9	11	13	14	15	16	17	19	20	23	23	16	99	310
160	5	7	4	10	12	13	14	15	16	17	19	20	23	23	16	99	313
180	5	7	5	11	12	13	14	15	16	17	19	20	23	23	16	99	315
200	5	7	7	11	12	13	14	15	16	17	19	20	23	23	16	99	317
220	5	7	9	11	12	13	14	15	16	17	19	20	23	23	16	99	319
240	5	7	11	11	12	13	14	15	16	17	19	20	23	23	16	99	321

Table 1–23a.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (310)																	
10	5	-----	-----	-----	0	0	0	7	0	0	2	3	3	5	10	52	87
20	5	-----	-----	-----	0	0	7	0	0	4	5	6	6	11	10	84	138
30	5	-----	-----	-----	0	7	0	0	5	5	7	8	9	14	12	96	168
40	5	-----	-----	-----	0	7	0	3	5	8	8	11	13	18	15	99	192
60	5	-----	-----	-----	0	7	3	6	7	10	12	18	22	23	16	99	228
80	5	-----	-----	-----	7	0	6	9	11	12	16	19	23	23	16	99	246
100	5	-----	-----	-----	7	1	9	10	14	17	19	20	23	23	16	99	263
120	5	-----	-----	-----	7	4	11	12	14	17	19	20	23	23	16	99	270
140	5	-----	-----	-----	7	5	12	15	16	17	19	20	23	23	16	99	277
160	5	-----	-----	-----	7	8	14	15	16	17	19	20	23	23	16	99	282
180	5	-----	-----	-----	7	10	14	15	16	17	19	20	23	23	16	99	284
200	5	-----	-----	-----	7	12	14	15	16	17	19	20	23	23	16	99	286
220	5	-----	-----	-----	8	13	14	15	16	17	19	20	23	23	16	99	288
240	5	-----	-----	-----	9	13	14	15	16	17	19	20	23	23	16	99	289
PARTIAL PRESSURE (320)																	
10	5	-----	-----	0	0	0	7	0	0	0	3	3	3	7	10	54	92
20	5	-----	-----	0	0	7	0	0	2	4	5	6	7	10	10	85	141
30	5	-----	-----	0	0	7	0	2	4	5	7	8	11	15	13	98	175
40	5	-----	-----	0	7	0	1	4	6	7	8	12	15	19	16	99	199
60	5	-----	-----	0	7	0	5	6	9	11	13	17	20	23	16	99	231
80	5	-----	-----	0	7	3	7	9	11	13	17	20	23	23	16	99	253
100	5	-----	-----	0	7	5	9	11	13	17	19	20	23	23	16	99	267
120	5	-----	-----	0	7	7	12	13	16	17	19	20	23	23	16	99	277
140	5	-----	-----	7	2	9	12	15	16	17	19	20	23	23	16	99	283
160	5	-----	-----	7	3	11	14	15	16	17	19	20	23	23	16	99	288
180	5	-----	-----	7	5	11	14	15	16	17	19	20	23	23	16	99	290
200	5	-----	-----	7	6	13	14	15	16	17	19	20	23	23	16	99	293
220	5	-----	-----	7	7	13	14	15	16	17	19	20	23	23	16	99	294
240	5	-----	-----	7	9	13	14	15	16	17	19	20	23	23	16	99	296
PARTIAL PRESSURE (330)																	
10	5	-----	-----	0	0	0	7	0	0	0	4	3	3	7	10	56	95
20	5	-----	-----	0	0	7	0	0	3	5	5	6	8	10	10	88	147
30	5	-----	-----	0	7	0	0	4	4	6	7	9	11	17	13	98	181
40	5	-----	-----	0	7	0	4	4	6	7	9	12	16	20	16	99	205
60	5	-----	-----	7	0	2	6	8	9	11	14	17	23	23	16	99	240
80	5	-----	-----	7	0	6	8	8	13	14	19	20	23	23	16	99	261
100	5	-----	-----	7	2	7	10	13	16	17	19	20	23	23	16	99	277
120	5	-----	-----	7	4	9	12	13	16	17	19	20	23	23	16	99	283
140	5	-----	-----	7	6	11	13	15	16	17	19	20	23	23	16	99	290
160	5	-----	-----	7	8	13	14	15	16	17	19	20	23	23	16	99	295
180	5	-----	-----	7	10	13	14	15	16	17	19	20	23	23	16	99	297
200	5	-----	-----	7	12	13	14	15	16	17	19	20	23	23	16	99	299
220	5	-----	-----	9	12	13	14	15	16	17	19	20	23	23	16	99	301
240	5	-----	-----	10	12	13	13	15	16	17	19	20	23	23	16	99	302

TABLE 1–23a.—*Helium-oxygen decompression table for exceptional exposures*—Continued

Time of dive	Time to first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
PARTIAL PRESSURE (340)																	
10	5	------	0	0	0	7	0	0	0	2	3	3	4	7	10	59	100
20	5	------	0	0	7	0	0	2	3	4	6	5	10	10	10	90	152
30	5	------	0	0	7	0	1	4	5	6	8	8	13	17	14	98	186
40	5	------	0	7	0	1	4	5	7	7	10	12	17	22	16	99	212
60	5	------	0	7	0	5	6	8	9	11	15	20	23	23	16	99	247
80	5	------	0	7	2	7	8	10	13	15	19	20	23	23	16	99	267
100	5	------	0	7	5	9	9	13	16	17	19	20	23	23	16	99	281
120	5	------	7	1	7	10	13	15	16	17	19	20	23	23	16	99	291
140	5	------	7	2	9	12	14	15	16	17	19	20	23	23	16	99	297
160	5	------	7	4	10	13	14	15	16	17	19	20	23	23	16	99	301
180	5	------	7	5	12	13	14	15	16	17	19	20	23	23	16	99	304
200	5	------	7	6	12	13	14	15	16	17	19	20	23	23	16	99	305
220	5	------	7	8	12	13	14	15	16	17	19	20	23	23	16	99	307
240	5	------	7	10	12	13	14	15	16	17	19	20	23	23	16	99	309
PARTIAL PRESSURE (350)																	
10	5	------	0	0	0	7	0	0	0	3	3	3	4	7	10	61	103
20	5	------	0	0	7	0	0	2	4	5	7	8	9	10	10	90	157
30	5	------	0	7	0	0	3	5	5	6	8	9	13	18	14	98	191
40	5	------	0	7	0	2	4	6	7	8	10	13	16	22	16	99	215
60	5	------	7	0	3	5	6	9	10	13	16	18	21	23	16	99	251
80	5	------	7	0	7	7	8	11	13	15	19	20	23	23	16	99	273
100	5	------	7	2	8	8	12	13	16	17	19	20	23	23	16	99	288
120	5	------	7	4	9	11	13	15	16	17	19	20	23	23	16	99	297
140	5	------	7	6	11	13	14	15	16	17	19	20	23	23	16	99	304
160	5	------	7	9	11	13	14	15	16	17	19	20	23	23	16	99	307
180	5	------	8	9	12	13	14	15	16	17	19	20	23	23	16	99	309
200	5	------	8	11	12	13	14	15	16	17	19	20	23	23	16	99	311
220	5	------	10	11	12	13	14	15	16	17	19	20	23	23	16	99	313
240	5	------	11	11	12	13	14	15	16	17	19	20	23	23	16	99	314
PARTIAL PRESSURE (360)																	
10	5	0	0	0	7	0	0	0	2	2	3	3	5	7	10	64	108
20	5	0	0	7	0	0	0	4	4	5	5	7	9	13	10	94	163
30	5	0	0	7	0	1	4	4	5	7	8	11	13	18	14	99	196
40	5	0	7	0	1	3	5	6	7	8	11	14	17	23	16	99	222
60	5	0	7	0	5	5	8	8	11	12	16	19	23	23	16	99	257
80	5	0	7	2	7	7	10	11	13	17	19	20	23	23	16	99	279
100	5	7	0	6	8	9	11	15	16	17	19	20	23	23	16	99	294
120	5	7	1	7	9	12	14	15	16	17	19	20	23	23	16	99	303
140	5	7	3	9	11	13	14	15	16	17	19	20	23	23	16	99	310
160	5	7	4	10	12	13	14	15	16	17	19	20	23	23	16	99	313
180	5	7	5	11	12	13	14	15	16	17	19	20	23	23	16	99	315
200	5	7	7	11	12	13	14	15	16	17	19	20	23	23	16	99	317
220	5	7	9	11	12	13	14	15	16	17	19	20	23	23	16	99	319
240	5	7	11	11	12	13	14	15	16	17	19	20	23	23	16	99	321

(FORMERLY TABLE 1-15, 1963 DIVING MANUAL)

TABLE 1–24.—*Emergency table* ($He\text{-}O_2$)

Depth (feet)	Time (min)
50	26
40	30
30	35
20	42
10	55

(FORMERLY TABLE 1-16, 1963 DIVING MANUAL)

TABLE 1–25.—*Emergency table* (*air*)

Stops (feet)	Depth up to (feet)—						
	100	150	200	250	300	350	400
230							
220							
210							
200							
190							3
180							11
170							12
160						9	12
150						13	13
140					4	13	14
130					14	15	15
120					16	16	16
110				13	16	17	17
100				18	18	18	18
90			7	19	19	20	20
80			22	22	22	22	22
70			24	24	24	24	24
60		22	26	26	26	27	27
50		30	30	30	30	30	30
40	14	35	35	35	35	35	35
30	42	42	42	42	42	42	42
20	52	52	52	52	52	52	52
10	68	68	68	68	68	68	68

$$\text{Maximum oxygen percentage} = \frac{(F \times 33)}{(D+33)}$$

where

D=gage depth in feet of sea water

F=maximum oxygen partial pressure in atmospheres from table 1–16

For a dive with a bottom time of 30 minutes or less, the permissible oxygen partial pressure in table 1–16 is 1.6 atmospheres absolute. In diving to 297 feet for 30 minutes or less, the maximum oxygen percentage would work out to be 16 percent according to the formula:

Maximum O_2 percentage

$$= \frac{(1.6 \times 33)}{(297+33)} = \frac{52.8}{330} = 0.16 = 16 \text{ percent}$$

Because 16 percent oxygen is the minimum oxygen percentage allowed in helium-oxygen deep-sea diving, 30 minutes is the maximum bottom time for a dive to 297 feet using these tables. Use of a breathing mixture with a smaller proportion of oxygen would expose the diver to the risk of decompression sickness.

Sequence of Computations

(5) Specific instructions are given on the use of the various tables. After determining the proper oxygen concentrations (1.5.4(4)), the general sequence of computations and the use of the tables are—

(*a*) Determine the partial pressure of all other gases (AOG), except oxygen, for the depth of the dive and the percentage of oxygen in the breathing medium. Compute by formula or use the Partial-Pressure Table.

(*b*) From knowledge of the partial pressure and the actual bottom time of the dive, select the proper decompression schedule. Use the Helium-Oxygen Decompression Table.

(*c*) Compute the rate of ascent to the first stop. Use the time listed in the "To First Stop" column of the proper decompression schedule.

(*d*) Remain at the first stop for the number of minutes specified.

(*e*) Ascend at the rate of 60 feet per minute between stops and remain at the stops the required number of minutes. Include each time of ascent in the subsequent stop.

(*f*) Shift to oxygen as the breathing medium at the 50-foot stop. Follow the outlined procedure.

(*g*) Use emergency tables if required.

Partial-Pressure Table

(6) The use of partial pressure of inert gas instead of actual depth of dive is the main difference between the air and helium-oxygen decompression methods. Table 1–22, "Table of Partial Pressures for Helium-Oxygen," provides the partial pressure of the inert gas. The table is based on the formula:

$$PP(AOG) = (D+33) \times (1.00 - (O_2 - 0.02))$$

where

PP(AOG) = partial pressure in feet of all other gases except oxygen

D = actual gage depth of water in feet

O_2 = decimal equivalent of oxygen percentage

0.02 = an assumed loss of 2 percent of oxygen in the helmet

Example: To dive to 290 feet with an 84 percent helium–16 percent oxygen mixture:

$$PP = (290+33) \times (1.00 - (0.16 - 0.02))$$
$$PP = 323 \times (1.00 - 0.14)$$
$$PP = 323 \times 0.86$$
$$PP = 277.8$$

Results are raised to the next larger even foot, so the partial pressure in the example would be 278 feet of sea water.

(7) When entering table 1–22, use the exact or next greater depth, the exact or next lesser oxygen percentage, and the exact or next greater partial pressure table obtained. Enter the table with the depth on the left side of the table. Follow across to the column headed by the average percentage oxygen of the bank in use. The table also gives 278 as the partial pressure (AOG) for a dive to 290 feet using 16 percent oxygen.

(8) It is also possible to interpolate exactly using table 1–17. For example, to dive to 195 feet with an 82-percent helium–18-percent oxygen mixture:

	17	18	19
190	190	188	186
195	194.5	192.3	190
200	199	196.5	194

(9) However, in such cases it is usually easier to use the formula:

$$PP = (195+33) \times (1.00 - (0.18 - 0.02))$$
$$PP = 228 \times (1.00 - 0.16)$$
$$PP = 228 \times 0.84$$
$$PP = 191.5 \text{ (which is raised to 192)}$$

(10) After the partial pressure of the gases used in the dive is determined either from table 1–22 or from the formula, the decompression schedule is chosen from table 1–23, "Helium-Oxygen Decompression Table."

Helium-Oxygen Decompression Tables

(11) There are two partial-pressure decompression tables in this manual. Table 1–23 is the Helium-Oxygen Decompression table, which shall be used for all routine diving operations. It contains schedules for each 10 feet of partial pressure from 60 to 290 feet, for varying bottom times in increments of about 10 minutes. The maximum bottom time given for each partial pressure is based upon the maximum allowable partial pressure of oxygen as dictated by table 1–16 if 16 percent oxygen is used in the breathing mixture. Note that this amount is also the minimum percentage of oxygen that can be used for helium-oxygen diving. If these schedules are properly followed, the incidence of decompression sickness should be mimimal.

(12) Table 1–23*a* is the *Helium-Oxygen Decompression Table for Exceptional Exposures*, and should never be used except in cases of extreme operational necessity or in the case of a fouled diver who has exceeded the maximum bottom time allowed by table 1–23. The use of these schedules for operational dives shall be directed only by the commanding officer of the diving activity involved, and he shall assume the responsibility for any mishap which might occur because of their use. The only exception to the above limitations is that these schedules may be used with discretion at the Naval School, Diving and Salvage, during certain phases of diver training. Decompression schedules are given for each 10 feet of partial pressure from 190 to 360 feet. If bottom times of 30 minutes or less are used, and if 16 percent oxygen is used as the supply gas, these tables will be within the exceptional oxygen limits of table 1–16*a*. Bottom times of greater than 30 minutes carry a large risk of oxygen toxicity. The evaluations of these tables for longer exposures have been inadequate, and there is some doubt as to their value.

(13) Details on the use of the Helium-Oxygen Decompression Table are—

(*a*) To obtain the decompression schedule, use the partial pressure group that is exactly equal to or is the next greater than that computed. Use the bottom time that is exactly equal to or is the next longer than the actual bottom time of the dive. Do not interpolate. Example: Assume

370–711 O—70——12

the time of the 290-foot dive above was 19 minutes. The partial pressure was 278, so the proper decompression schedule is a partial pressure of *280* and a bottom time of *20*.

(*b*) Obtain the rate of ascent to the first stop by dividing the distance in feet from the bottom to the first stop by the number of minutes listed in the "To First Stop" column of the proper decompression schedule. Example: Use the dive and the decompression schedule above. The distance to the first stop is 297 − 120 = 177 feet. The "4" listed in the "To First Stop" column means that you are to take 4 minutes for ascent. Divide 177 by 4 and obtain the rate of ascent, which is approximately 44 feet per minute.

(*c*) Remain at the first stop for the number of minutes specified (usually 7).

(*d*) The rate of ascent between subsequent stops is 60 feet per minute. Include the time spent during ascent and the time spent at the subsequent stop in the total time specified for the stop. Example: The rate of ascent between the first and second stops for the 290-foot/19-minute dive is 60 feet per minute. At that rate, you will use 30 seconds ascending from 120 feet to 90 feet. After arrival at the 90-foot stop, stay 1½ minutes to comply with the 2 minutes specified. The easiest way to time this period is to start a stopwatch at the time of leaving each stop. Leave the next stop after the specified number of minutes.

(*e*) The steps to accomplish the shift to oxygen at the 50-foot stop are given in part 2.

(*f*) Surface at a uniform rate during the last minute of decompression time.

Rate of Ascent

(14) The rate of ascent to the first stop is computed from the Helium-Oxygen Decompression Table. The rate of ascent between the rest of the stops is a uniform 60 feet per minute.

Emergency Table (He-O_2)

(15) In an emergency it may happen that oxygen cannot be used for decompression, owing to failure of the oxygen supply or to symptoms of oxygen poisoning. Either air or helium-oxygen mixtures must then be used. The procedure for use of helium-oxygen is immediately available in table 1–24.

(16) If the impossibility of using oxygen is known in advance, use the regular schedule up to the first oxygen stop, then shift to the Emergency Table (He-O_2). The procedure is obvious. (If the development of symptoms requires a shift *during* oxygen breathing, use the procedure described in 1.5.4(21).)

Emergency Table (Air)

(17) The procedure for the use of air in an emergency prohibiting the use of oxygen or helium-oxygen is immediately available in table 1–25.

(18) The decompression can be calculated for each case. However, because the emergency may occur at any point from the bottom to the last stop, it is impractical to attempt to cover all of the possibilities in a table. In the event of an emergency in helium-oxygen diving, begin ascent immediately. The rate of ascent to the first stop as listed in the emergency tables should comply with the rate of ascent to the first stop as listed in the partial pressure tables, but it should not normally exceed 60 feet per minute. The rate of ascent on subsequent stops using emergency tables is not critical, as long as full decompression is received at each stop.

(19) The table is simple. Schedules are provided for each 50 feet. Select the one next deeper than the actual depth, unless the actual depth is exactly at an even 50-foot figure.

(20) The diving chart—He-O_2, which is illustrated in figure 1–32—should be used for assistance in conducting a helium-oxygen dive. The chart provides spaces for information required to determine the dive schedule and for the recording of information required for the dive record. Place the time at stops as determined from table 1–23 in the column marked "Time to first stop." Place the time at stops as determined from table 1–25 in the "Emergency Air" column. All information should be filled out on the chart to insure a complete record, and to insure the availability of emergency table without further reference to the Diving Manual during the dive.

Oxygen Poisoning

(21) If the diver reports symptoms of *oxygen poisoning during oxygen decompression:*

DIVING CHART - HE-O_2 NAVSHIPS [illegible] S/N 0105-643-3200 | DATE

NAME	DATE	TABLE USED	SCHEDULE USED	MAXIMUM O_2	EFFECT. ATMOS.	CUT OFF DEPTH
LEFT SURFACE	REACHED BOTTOM	LEFT BOTTOM	TIME TO FIRST STOP	BOTTOM TIME	PRESSURE IN PSI	
DEPTH IN FEET / O_2%	TOTAL DECOMP. TIME	TOTAL TIME OF DIVE	COMP. OF TABLE	TENDER (Sign name)		

DESCENT ASCENT	EMERG. AIR	DEPTH OF STOPS FT.	DECOMPRESSION TIME AT STOP	EMERG HE-O_2	PRESSURE IN PSI	TIME	RATE OF ASCENT IN FPM
		200			89	R / L	
		190			86	R / L	
		180			80	R / L	
		170			75	R / L	
		160			72	R / L	
		150			67	R / L	
		140			62	R / L	
		130			58	R / L	
		120			54	R / L	
		110			49	R / L	
		100			44.5	R / L	
		90			40	R / L	
		80			36	R / L	
		70			32	R / L	
		60			27	R / L	
		50		26	22	R / L	
			WATER / CHAMBER			WATER / CHAMBER	
		40		30	18	R / L	
		30		35	13	R / L	
		20		42	9	R / L	
		10		55	4.5	R / L	
REACHED SURFACE	DIVER'S CONDITION AND REMARKS						

FIGURE 1-32.—Diving chart—He-O_2.

(*a*) If the diver is within 5 minutes of completing required water stops for surface decompression (see 1. 5. 5 (17) and (18)):

1. Start ascent at once.

2. Place diver in chamber immediately.

3. Proceed with surface decompression.

4. Double the missed time and add to chamber stop.

5. Use oxygen in chamber, but watch carefully for reappearance of symptoms.

6. Keep diver close to chamber following decompression and observe carefully for symptoms of decompression sickness.

(*b*) If prompt ascent for surface decompression is *not* allowable:

1. Bring the diver up 10 feet at once.

2. Promptly shift to air.

3. Have the diver open the exhaust valve, ventilate, and remain on open circuit.

4. Be alert for possible blowup.

5. Complete decompression according to the Emergency Air Table.

6. Bring the diver up for surface decompression following the completion of the 30-foot stop listed on the Emergency Table, if desired. Take the diver to 40 feet in the chamber, and complete the decompression with oxygen as if oxygen had been used throughout.

(*c*) If symptoms proceed to convulsion in spite of the measures taken:

1. Bring the diver to the surface at a moderate rate.

2. Place him in a recompression chamber at once.

3. Take him to 165 feet. (See tables 1–30 and 1–31.)

4. Follow Treatment Table 3, 4, or 6A, depending on the diver's condition at the end of 30 minutes at 165 feet.

NOTE

The danger of causing air embolism by bringing the diver up during a convulsion caused by oxygen decompression is outweighed by the dangers of failing to do so. Since the possibility that air embolism has occurred cannot be ruled out in these cases, they require treatment for such.

1.5.5 SURFACE DECOMPRESSION

(1) In surface-decompression procedures, stage decompression in the water is reduced to a minimum or is eliminated, and the major part of decompression is accomplished in a recompression chamber on the surface. Oxygen is the standard breathing medium during the decompression period on the surface. Air or gas mixtures are alternate breathing mediums. There are separate decompression tables and procedures which apply specifically to the breathing medium used.

(2) In the U.S. Navy at present, surface decompression procedures expose the diver to atmospheric pressure for a *brief surface interval* between his leaving the water and his attaining the scheduled decompression-stop depth in the recompression chamber. The interval *must* be as short as possible.

(3) The principal advantages of surface decompression are the comfort and security provided to the diver by allowing him to surface in case of extremely cold or rough sea, physical exhaustion, and the like. In certain dives, surface decompression with pure oxygen has the additional advantage of saving an appreciable amount of the total decompression time required for straight air decompression.

(4) Surface decompression schedules may be applied to emergencies where a surface interval *must* come between the dive and the major part of the decompression. Such cases may be emergencies forcing unscheduled surfacing (1.5.6 (1)), or situations in scuba diving when the diver *must* surface to obtain a new air supply (1.5.5(9)). Although it is possible, when air is the breathing medium, for the decompression period following the surface interval to be in the water, *recompression in a chamber (if available) is always to be preferred.*

Oxygen Following an Air Dive

(5) If a recompression chamber is available and is equipped with proper oxygen-breathing equipment (1.6.18(17)), the procedure outlined in the Surface Decompression Table Using Oxygen (table 1–26) may be used in a routine manner. Follow the instructions accurately and take all precautions to insure that only pure oxygen is breathed. Maintain *breathing* equipment in perfect working condition to insure successful results from this table.

(6) In the event of oxygen toxicity symptoms, or failure of the oxygen supply, give

(FORMERLY TABLE 1-17, 1963 DIVING MANUAL)

TABLE 1-26.—*Surface decompression table using oxygen*

1	2	3	4				5	6	7	8
Depth (ft, gage)	Bottom time (min) [1]	Time to first stop or surface [2]	Time (min) breathing air at water stops (ft) [3]				Surface interval [4]	Time at 40-foot chamber stop (min) on oxygen [5]	Surface [6]	Total decompression time (min: sec) [7]
			60	50	40	30				
70	52	2:48	0	0	0	0	SURFACE INTERVAL NOT TO EXCEED 5 MINUTES	0	2-MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	2:48
	90	2:48	0	0	0	0		15		23:48
	[8] 120	2:48	0	0	0	0		23		31:48
	150	2:28	0	0	0	0		31		39:48
	180	2:48	0	0	0	0		39		47:48
80	40	3:12	0	0	0	0		0		3:12
	70	3:12	0	0	0	0		14		23:12
	85	3:12	0	0	0	0		20		29:12
	100	3:12	0	0	0	0		26		35:12
	[8] 115	3:12	0	0	0	0		31		40:12
	130	3:12	0	0	0	0		37		46:12
	150	3:12	0	0	0	0		44		53:12
90	32	3:36	0	0	0	0		0		3:36
	60	3:36	0	0	0	0		14		23:36
	70	3:36	0	0	0	0		20		29:36
	80	3:36	0	0	0	0		25		34:36
	[8] 90	3:36	0	0	0	0		30		39:36
	100	3:36	0	0	0	0		34		43:36
	110	3:36	0	0	0	0		39		48:36
	120	3:36	0	0	0	0		43		52:36
	130	3:36	0	0	0	0		48		57:36
100	26	4:00	0	0	0	0		0		4:00
	50	4:00	0	0	0	0		14		24:00
	60	4:00	0	0	0	0		20		30:00
	70	4:00	0	0	0	0		26		36:00
	[8] 80	4:00	0	0	0	0		32		42:00
	90	4:00	0	0	0	0		38		48:00
	100	4:00	0	0	0	0		44		54:00
	110	4:00	0	0	0	0		49		59:00
	120	4:00	0	0	0	0		53		63:00
110	22	4:24	0	0	0	0		0		4:24
	40	4:24	0	0	0	0		12		22:24
	50	4:24	0	0	0	0		19		29:24
	60	4:24	0	0	0	0		26		36:24
	[8] 70	4:24	0	0	0	0		33		43:24
	80	3:12	0	0	0	1		40		51:12
	90	3:12	0	0	0	2		46		58:12
	100	3:12	0	0	0	5		51		66:12
	110	3:12	0	0	0	12		54		76:12
120	18	4:48	0	0	0	0		0		4:48
	30	4:48	0	0	0	0		9		19:48
	40	4:48	0	0	0	0		16		26:48
	50	4:48	0	0	0	0		24		34:48
	[8] 60	3:36	0	0	0	2		32		44:36
	70	3:36	0	0	0	4		39		53:36
	80	3:36	0	0	0	5		46		61:36
	90	3:12	0	0	3	7		51		72:12
	100	3:12	0	0	6	15		54		86:12
130	15	5:12	0	0	0	0		0		5:12
	30	5:12	0	0	0	0		12		23:12
	40	5:12	0	0	0	0		21		32:12
	50	4:00	0	0	0	3		29		43:00
	[8] 60	4:00	0	0	0	5		37		53:00
	70	4:00	0	0	0	7		45		63:00
	80	3:36	0	0	6	7		51		75:36
	90	3:36	0	0	10	12		56		89:36

See footnotes at end of table.

TABLE 1–26.—*Surface decompression table using oxygen*—Continued

1 Depth (ft, gage)	2 Bottom time (min) [1]	3 Time to first stop or surface [2]	4 Time (min) breathing air at water stops (ft) [3] 60	 50	 40	 30	5 Surface interval [4]	6 Time at 40-foot chamber stop (min) on oxygen [5]	7 Surface [6]	8 Total decompression time (min: sec) [7]
140	13	5:36	0	0	0	0	SURFACE INTERVAL NOT TO EXCEED 5 MINUTES	0	2-MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	5:36
	25	5:36	0	0	0	0		11		22:36
	30	5:36	0	0	0	0		15		26:36
	35	5:36	0	0	0	0		20		31:36
	40	4:24	0	0	0	2		24		37:24
	45	4:24	0	0	0	4		29		44:24
	50	4:24	0	0	0	6		33		50:24
	[8] 55	4:24	0	0	0	7		38		56:24
	60	4:24	0	0	0	8		43		62:24
	65	4:00	0	0	3	7		48		70:00
	70	3:36	0	2	7	7		51		79:36
150	11	6:00	0	0	0	0		0		6:00
	25	6:00	0	0	0	0		13		25:00
	30	6:00	0	0	0	0		18		30:00
	35	4:48	0	0	0	4		23		38:48
	40	4:24	0	0	3	6		27		48:24
	45	4:24	0	0	5	7		33		57:24
	[8] 50	4:00	0	2	5	8		38		66:00
	55	3:36	2	5	9	4		44		77:36
160	9	6:24	0	0	0	0		0		6:24
	20	6:24	0	0	0	0		11		23:24
	25	6:24	0	0	0	0		16		28:24
	30	5:12	0	0	0	2		21		35:12
	35	4:48	0	0	4	6		26		48:48
	40	4:24	0	3	5	8		32		61:24
	[8] 45	4:00	3	4	8	6		38		73:00
170	7	6:48	0	0	0	0		0		6:48
	20	6:48	0	0	0	0		13		25:48
	25	6:48	0	0	0	0		19		31:48
	30	5:12	0	0	3	5		23		44:12
	35	4:48	0	4	4	7		29		57:48
	[8] 40	4:24	4	4	8	6		36		72:24

[1] Time interval in minutes from leaving the surface to leaving the bottom.

[2] Time of ascent in minutes and seconds to the first stop or to the surface at a rate of 25 feet per minute.

[3] Water stops: Time spent at tabulated stops using air. If no water stops are required, use a 25-foot-per-minute rate of ascent to the surface. When water stops are required, use a 25-foot-per-minute rate of ascent to the first stop. Take an additional minute between stops. Use 1 minute for the ascent from 30 feet to the surface.

[4] Surface interval: The surface interval shall not exceed 5 minutes and is composed of the following elements:

a. Time of ascent from the 30-foot water stop to the surface (1 minute).

b. Time on the surface for landing the diver on deck and undressing (not to exceed 3 minutes and 30 seconds).

c. Time of descent in the recompression chamber from the surface to 40 feet (about 30 seconds).

[5] During the period of oxygen breathing, the chamber shall be ventilated unless an oxygen-elimination system is used.

[6] Surfacing: Oxygen breathing during this 2-minute period shall follow without interruption the period of oxygen breathing tabulated in col. 6.

[7] Total decompression time in minutes and seconds. This time includes:

a. Time of ascent from the bottom to the first stop at 25 feet per minute, col. 3.

b. Sum of tabulated water stops, col. 4.

c. One minute between water stops.

d. The surface interval, col. 5.

e. Time at 40 feet in the recompression chamber, col. 6.

f. Time of ascent, an additional 2 minutes, from 40 feet to the surface, col. 7.

The total decompression time may be shortened only by decreasing the time required to undress the diver on deck.

[8] These are the optimum exposure times for each depth and represent for the average diver the best balance of safety, length of work period, and amount of useful work. Exposure beyond these limits of time is permitted only under special conditions.

(FORMERLY TABLE 1-18, 1963 DIVING MANUAL)

TABLE 1-27.—*Surface decompression table using air*

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min)				Chamber stops (air) (min)		Total ascent time (min:sec)
			30	20	10		20	10	
40	230	0:30			3	TIME ON SURFACE NOT TO EXCEED 3 MINUTES AND 30 SECONDS		7	14:30
	250	:30			3			11	18:30
	270	:30			3			15	22:30
	300	:30			3			19	26:30
50	120	:40			3			5	12:40
	140	:40			3			10	17:40
	160	:40			3			21	28:40
	180	:40			3			29	36:40
	200	:40			3			35	42:40
	220	:40			3			40	47:40
	240	:40			3			47	54:40
60	80	:50			3			7	14:50
	100	:50			3			14	21:50
	120	:50			3			26	33:50
	140	:50			3			39	46:50
	160	:50			3			48	55:50
	180	:50			3			56	63:50
	200	:40		3			3	69	80:10
70	60	1:00			3			8	16:00
	70	1:00			3			14	22:00
	80	1:00			3			18	26:00
	90	1:00			3			23	31:00
	100	1:00			3			33	41:00
	110	:50		3			3	41	52:20
	120	:50		3			4	47	59:20
	130	:50		3			6	52	66:20
	140	:50		3			8	56	72:20
	150	:50		3			9	61	78:20
	160	:50		3			13	72	93:20
	170	:50		3			19	79	106:20
80	50	1:10			3			10	18:10
	60	1:10			3			17	25:10
	70	1:10			3			23	31:10
	80	1:00		3			3	31	42:30
	90	1:00		3			7	39	54:30
	100	1:00		3			11	46	65:30
	110	1:00		3			13	53	74:30
	120	1:00		3			17	56	81:30
	130	1:00		3			19	63	90:30
	140	1:00		26			26	69	126:30
	150	1:00		32			32	77	146:30
90	40	1:20			3			7	15:20
	50	1:20			3			18	26:20
	60	1:20			3			25	33:20
	70	1:10		3			7	30	45:40
	80	1:10		13			13	40	71:40
	90	1:10		18			18	48	89:40
	100	1:10		21			21	54	101:40
	110	1:10		24			24	61	114:40
	120	1:10		32			32	68	137:40
	130	1:00	5	36			36	74	156:40

TABLE 1-27.—*Surface decompression table using air*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min)						Chamber stops (air) (min)		Total ascent time (min:sec)
			50	40	30	20	10		20	10	
100	40	1:30					3	TIME ON SURFACE NOT TO EXCEED 3 MINUTES AND 30 SECONDS		15	23:30
	50	1:20				3			3	24	35:50
	60	1:20				3			9	28	45:50
	70	1:20				3			17	39	64:50
	80	1:20				23			23	48	99:50
	90	1:10			3	23			23	57	111:50
	100	1:10			7	23			23	66	124:50
	110	1:10			10	34			34	72	155:50
	120	1:10			12	41			41	78	177:50
	30	1:40					3			7	15:40
	40	1:30				3			3	21	33:00
	50	1:30				3			8	26	43:00
	60	1:30				18			18	36	78:00
	70	1:20			1	23			23	48	101:00
	80	1:20			7	23			23	57	116:00
110	90	1:20			12	30			30	64	142:00
	100	1:20			15	37			37	72	167:00
120	25	1:50					3			6	14:50
	30	1:50					3			14	22:50
	40	1:40				3			5	25	39:10
	50	1:40				15			15	31	67:10
	60	1:30			2	22			22	45	97:10
	70	1:30			9	23			23	55	116:10
	80	1:30			15	27			27	63	138:10
	90	1:30			19	37			37	74	173:10
	100	1:30			23	45			45	80	189:10
130	25	2:00					3			10	19:00
	30	1:50				3			3	18	30:20
	40	1:50				10			10	25	51:20
	50	1:40			3	21			21	37	88:20
	60	1:40			9	23			23	52	113:20
	70	1:40			16	24			24	61	131:20
	80	1:30		3	19	35			35	72	170:20
	90	1:30		8	19	45			45	80	203:20
140	20	2:10					3			6	15:10
	25	2:00				3			3	14	26:30
	30	2:00				5			5	21	37:30
	40	1:50			2	16			16	26	66:30
	50	1:50			6	24			24	44	104:30
	60	1:50			16	23			23	56	124:30
	70	1:40		4	19	32			32	68	161:30
	80	1:40		10	23	41			41	79	200:30
150	20	2:10				3			3	7	19:40
	25	2:10				4			4	17	31:40
	30	2:10				8			8	24	46:40
	40	2:00			5	19			19	33	82:40
	50	2:00			12	23			23	51	115:40
	60	1:50		3	19	26			26	62	142:40
	70	1:50		11	19	39			39	75	189:40
	80	1:40	1	17	19	50			50	84	227:40
160	20	2:20				3			3	11	23:50
	25	2:20				7			7	20	40:50
	30	2:10			2	11			11	25	55:50
	40	2:10			7	23			23	39	98:50
	50	2:00		2	16	23			23	55	125:50
	60	2:00		9	19	33			33	69	169:50
	70	1:50	1	17	22	44			44	80	214:50
170	15	2:30				3			3	5	18:00
	20	2:30				4			4	15	30:00
	25	2:20			2	7			7	23	46:00
	30	2:20			4	13			13	26	63:00
	40	2:10		1	10	23			23	45	109:00
	50	2:10		5	18	23			23	61	137:00
	60	2:00	2	15	22	37			37	74	194:00
	70	2:00	8	17	19	51			51	86	239:00

TABLE 1–27.—*Surface decompression table using air*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min)						Chamber stops (air) (min)		Total ascent time (min:sec)
			50	40	30	20	10		20	10	
180	15	2:40	....	....	....	3	....	TIME ON SURFACE NOT TO EXCEED 3 MINUTES AND 30 SECONDS	3	6	19:10
	20	2:30	....	....	1	5	....		5	17	35:10
	25	2:30	....	....	3	10	....		10	24	54:10
	30	2:30	....	....	6	17	....		17	27	74:10
	40	2:20	....	3	14	23	....		23	50	120:10
	50	2:10	2	9	19	30	....		30	65	162:10
	60	2:10	5	16	19	44	....		44	81	216:10
190	15	2:50	....	....	....	4	....		4	7	22:20
	20	2:40	....	....	2	6	....		6	20	41:20
	25	2:40	....	....	5	11	....		11	25	59:20
	30	2:30	....	1	8	19	....		19	32	86:20
	40	2:30	....	8	14	23	....		23	55	130:20
	50	2:20	4	13	22	33	....		33	72	184:20
	60	2:20	10	17	19	50	....		50	84	237:20

NOTE.—The ascent rates in this table are 60 feet per minute to the first stop, between stops and to the surface in the water and in the chamber. The descent rate in the chamber is also 60 feet per minute. The total ascent time may be shortened only by shortening the surface interval.

decompression in accordance with table 1–27, disregarding time spent on oxygen.

(7) Table 1–26 has not been recomputed in accordance with the concepts established in the calculation of the Standard Air Decompression Tables. There are some discrepancies in the limits of allowable exposures. However, this table is considered to be safe in its present form. Note that ascent at the rate of 25 feet per minute is required for the initial ascent when this table is used.

Air Following an Air Dive

(8) The Surface Decompression Table Using Air (table 1–27) may be used in any situation that requires surface decompression when the breathing of oxygen in a chamber is impossible. Because there is no saving of time over ordinary decompression methods, the comfort and security of the diver are the only advantages in the use of this surface decompression method.

(9) In self-contained diving, it may be impossible for the diver to carry a sufficient air supply for the duration of the entire dive and the standard decompression. If this situation occurs, the diver may surface (in accordance with either table 1–26 or 1–27) and receive the major part of his decompression in a recompression chamber. If no chamber is available, he may take (in accordance with table 1–27) the water stops in the water, surface, obtain a new air supply, and return in the water to the scheduled stop depths. However, providing *surface-supplied air or extra air cylinders* for use at the decompression stop depth, with decompression according to standard tables, is a safer and more reasonable procedure.

(10) Table 1–27 requires repetition of one stop and increases by that amount the total decompression time required by the same schedule in the Standard Air Decompression Table. There is no procedure for surface decompression following a dive on the Standard Air Decompression Table for Exceptional Exposures.

(11) Ascend from the last water stop to the surface at the rate of 60 feet per minute. Keep the time on the surface to the absolute minimum. Do not exceed the 3½-minute limit. Descend to the first chamber stop at the normal rate.

Oxygen Following a Nitrogen-Oxygen Dive

(12) Table 1–26 or table 1–27 may be used routinely for decompression from dives using nitrogen-oxygen mixtures as the breathing medium.

(13) After the corresponding equivalent air depth is determined in accordance with the procedure outlined in 1.5.3, table 1–26 or table 1–27 may be used in the standard manner.

Air Following a Nitrogen-Oxygen Dive

(14) All the previous statements relative to the use of air in surface decompression apply to nitrogen-oxygen mixed-gas diving.

(15) A high oxygen percentage mixture of nitrogen-oxygen is more efficient than air as a

breathing medium for surface decompression. Use it if it is available, but the same restrictions and precautions applicable to air apply to these mixtures as well.

Oxygen Following a Helium-Oxygen Dive

(16) Recompression chambers equipped with oxygen are available at any helium-oxygen diving operation. Surface decompression may be used as a routine procedure, as described in the following paragraphs.

(17) In tables where the first stop is 40 feet, bring the diver to 40 feet, shift his breathing medium to oxygen, and have him remain at 40 feet for 10 minutes. Surface the diver in 1 minute and return him to 40 feet in the recompression chamber on oxygen for the full time of the 40-foot stop. Not more than 5 minutes should elapse from the time the diver leaves the water stop to the time he reaches the chamber stop. During the last 5 minutes of decompression time, surface the diver at a uniform rate.

Example:

Partial pressure	100
Time of dive (minutes)	40
Time (minutes):	
Leave bottom	0
Reach 40	3
Ventilate 25 cubic feet of oxygen.	
Leave 40	13
Reach surface	14
Leave surface	16
Reach 40	16½
Leave 40	42½
Reach surface	47½

(18) In tables where the first stop is other than 40 feet, give decompression as listed until the diver reaches the 40-foot stop. Have him remain at 40 feet for a length of time equal to that of the 50-foot stop. Surface the diver in 1 minute and return him to 40 feet in the recompression chamber on oxygen for the full time of the 40-foot stop. Not more than 5 minutes should elapse from the diver's leaving the water stop to his reaching the chamber stop. During the last 5 minutes of decompression time, surface the diver at a uniform rate.

Example:

Partial pressure	160
Time of dive (minutes)	40
Leave bottom	0
Reach 60	3

Example—Continued

Leave 60	10
Reach 50	10½
Ventilate 25 cubic feet of oxygen.	
Leave 50	20
Reach 40	20½
Leave 40	30
Reach surface	31
Leave surface	32½
Reach 40	33
Leave 40	93
Reach surface	98

Air or Helium-Oxygen Following a Helium-Oxygen Dive

(19) The use of air or helium-oxygen mixtures during surface decompression from a helium-oxygen dive is strictly an emergency procedure. The instructions in 1.5.4 (15 to 17) on emergency shifts to air or helium-oxygen mixtures apply to surface decompression.

1.5.6 OMITTED DECOMPRESSION IN EMERGENCIES

(1) Certain emergencies may interrupt or prevent specified decompression. Blowup, complete loss of communication without a standby diver, exhausted air supply, bodily injury, and the like are among such emergencies. If there are symptoms of decompression sickness or air embolism, immediate treatment by recompression (tables 1–30 and 1–31) is essential. Even without evidence of any ill effects, omitted decompression must be made up in some manner to avert later difficulty.

Use of Surface Decompression Tables

(2) It may *appear* that surface decompression schedules offer an immediate solution to the problem of interrupted decompression because they provide for a surface interval. Such schedules should *only* be used, however, *if the emergency surface interval occurs at such a time that water stops are not required or have already been completed* in accordance with whichever surface decompression table is considered most appropriate.

Surface Decompression Tables Not Applicable

(3) When the conditions in paragraph (2) above are *not* fulfilled, the diver's decompres-

sion has been compromised. Special care should be taken to detect signs of decompression sickness regardless of what action is initiated. The diver must be returned to pressure as soon as possible. The use of a recompression chamber, if available, is always preferable to water decompression.

When a Recompression Chamber Is Available

(4) Even if the diver shows no ill effects from his omitted decompression, he needs immediate recompression. Take him to 100 feet in the chamber and keep him at that depth for 30 minutes. If he still shows no ill effects after that period of time, bring him out of the chamber in accordance with Treatment Table 1 or 1A (table 1–30). Consider any decompression sickness developing during or after this procedure as a recurrence (table 1–32).

When No Chamber Is Available

(5) Recompress the diver in the water, following as nearly as possible the procedure in paragraph (4) above. Keep the diver at rest, provide a standby diver, and maintain good communication and depth control.

(6) When the course of action outlined in paragraph (5) above is impossible, use the following procedure, which is based on the Standard Air Decompression Table with 1 minute between stops:

(*a*) Repeat any stops deeper than 40 feet.

(*b*) At 40 feet, remain for one-fourth of the 10-foot stop time.

(*c*) At 30 feet, remain for one-third of the 10-foot stop time.

(*d*) At 20 feet, remain for one-half of the 10-foot stop time.

(*e*) At 10 feet, remain for 1½ times the scheduled 10-foot stop time.

1.5.7 OXYGEN LIMITS

(1) Exposure to oxygen for 30 minutes at 60 feet is used as the routine oxygen tolerance test, and exposures of this depth and duration are used in the treatment of decompression sickness. In decompression from helium-oxygen dives, oxygen is breathed at depths as great as 50 feet. *Such exposures are safe only if the diver is at rest.* This section concerns exposure limits for *working dives* in which oxygen is the breathing medium. The limits established to provide safety from oxygen poisoning anticipate exceptional operational requirements and emergencies as well as normal requirements.

(2) The system is composed of three parts. The first limit is based on normal, uncomplicated daily requirements. The second limit is considered sufficiently safe for exceptional operational requirements, and the third limit is a summary of experience at the higher oxygen tensions. It is actually a warning of the results to expect and to prepare for.

(3) These limits are applicable mainly to diving with pure oxygen. The depth limits for diving with nitrogen-oxygen and helium-oxygen mixtures are discussed in 1.5.3 and 1.5.4 and establish the oxygen limits during use of those mixtures.

(4) The potential results from oxygen poisoning at depth are so serious, and so many uncontrolled variables are present, that a relatively safe limit is necessary for normal operations. The importance of the amount of physical exertion and of excess carbon dioxide, along with other physiological factors, is explained in 1.3.11. Review that entire section before diving with a high partial pressure of oxygen.

Normal Oxygen Limit

(5) The normal limit is straightforward. When using oxygen as the breathing medium, DO NOT DIVE DEEPER THAN 25 FEET (stay within the time limits in table 1–28).

Limits for Exceptional Operations (Important Operation Limit)

(6) Provided that all other variables are optimum, tests indicate that short exposures at depths greater than 25 feet are safe. The diving officer may authorize use of the depth-time limits given in table 1–28 for depths greater than 25 feet when he has weighed his operational objectives against the increased hazards and has taken all precautions possible.

(FORMERLY TABLE 1-19, 1963 DIVING MANUAL)

TABLE 1-28.—*Oxygen depth-time limits*

[Depth and time limits of exposure for breathing pure oxygen during working dives]

1. Normal oxygen limits—*Do not dive deeper than 25 feet.* Observe these time limits:

Depth (ft)	Time (min)
10	240
15	150
20	110
25	75

2. Limits for exceptional operations:

Depth (ft)	Time (min)
30	45
35	25
40	10

3. Emergency limits. (See art. 1.5.7, par. (7), and fig. 1-33.)

Emergency Limit

(7) Extraordinary situations, such as the requirement for an extremely important mission when oxygen is the only breathing medium that can be used, might dictate that an attempt be made to exceed the limits of table 1-28. These paragraphs present the odds for and against success.

(8) Figure 1-33 shows the results of experimental exposures to pure oxygen at various depths for various times. The proximity of possible warning symptoms and even convulsions to the Important Operation Limit Curve is apparent. Less apparent is the contrast between the perfect conditions that existed during these exposures and the conditions that would probably exist in the field. The experiments were conducted in a pressure tank; the work rates were moderate and uniform; the inspired gas was free of carbon dioxide; and two tenders were standing by each subject. It is likely that exposure to oxygen at these depths for the same times under operating conditions would produce a much larger proportion of unfavorable effects.

(9) The necessity to exceed the limits of table 1-28 in order to accomplish a mission must be brought to the attention of the officer assigning the mission, who must accept the responsibility for the increased hazard to personnel.

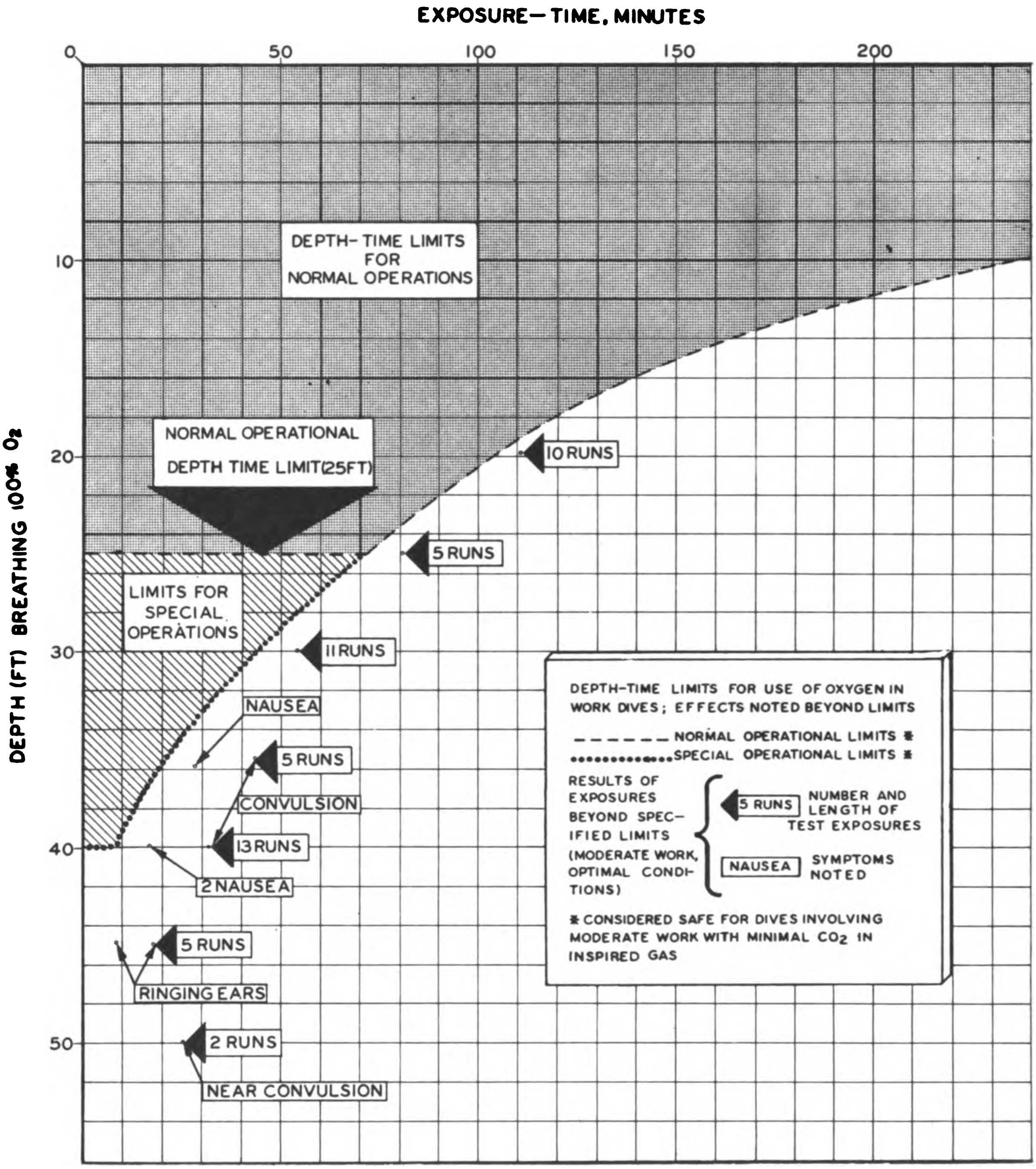

FIGURE 1-33.—Oxygen depth-time limits.

SECTION 1.6 DIVING HAZARDS

1.6.1 INTRODUCTION

General

(1) Diving confronts man with forces and physiological effects that are not encountered in his normal environment. These forces impose definite limits and can cause serious accidents. The diver's safety depends upon his knowledge of these factors and his ability to recognize and handle them.

Recognition and Management of Hazards

(2) The discussions on physics and physiology have made you aware of most of the potential hazards of diving. The purpose of this chapter is to give you knowledge which will help you to avoid hazards whenever possible, to cope with hazards which cannot be avoided, and to recognize and treat accidents when they occur. It permits you to evaluate the factors of environment, of specific equipment, and of your own condition in relation to each job. *Ignorance is the diver's worst enemy.* Many potential dangers can almost completely be avoided if they are recognized. To cite one example, many amateur divers would be alive today if they had known that holding their breath on ascent would cause air embolism. Even after such an accident occurred, many of these lives could have been saved if anyone nearby had recognized the condition and had been able to provide proper treatment.

(3) You will meet with many unavoidable hazards, but awareness and understanding will permit you to face them with a minimum of risk. Under combat conditions, some of these hazards are likely to be increased and diving must be performed under conditions which would be otherwise unacceptable.

(4) When a dangerous condition is developing in yourself, your buddy, or the man you are tending or supervising, active *awareness* promotes early recognition of danger and enables you to take immediate corrective action. As a diver, you must know the *causes*, *symptoms*, and *signs* of diving accidents so that proper actions or treatment can be commenced without delay.

(5) In the following discussions of accidents, the words *symptom* and *sign* will be used frequently. The following explanation is given to clarify their meanings as used in this manual: *Symptom* refers to those sensations experienced by the diver. *Sign* refers to those changes which can be observed by another person. A symptom can also be a sign. For example, a diver may complain of an inability to move his leg. This is a symptom. The observer might see limping or the inability to lift that leg. These are signs. Pain is purely a symptom, because the observer cannot feel or see it. He may see evidence of it, such as wincing or grimacing, but the observer cannot determine the existence of a symptom such as pain other than by the report of the patient. This differentiation between signs and symptoms adds to the awareness of the diver. Such awareness becomes particularly important in the use of scuba, because the individual and his buddy must protect not only themselves but also each other. The diver must be able to recognize *symptoms* in himself and must also be able to recognize *signs* of early stages of accidents in his buddy so that prompt corrective action may be taken.

(6) When a hazard is encountered or an accident occurs, you must take all possible action to prevent further development of the condition. You must know the proper treatment of a condition which has already developed. In order to accomplish treatment, you must be familiar with the proper operation of such specialized equipment as recompression chambers and resuscitators. In addition, knowledge of manual artificial-respiration methods and first-aid principles must be a part of your ability to cope with diving accidents. You must know how to trans-

port casualties properly, taking into consideration problems of pressure and good first-aid technique.

1.6.2 DECOMPRESSION SICKNESS

(1) As previously discussed, decompression sickness is the result of the formation of gas bubbles in the blood or tissues. Decompression sickness can occur only when decompression (a reduction in the pressure surrounding the body) has taken place—as when a diver comes up from depth or when an aviator goes up to high altitude. Decompression sickness will not occur unless there is an excessive amount of inert gas dissolved in the blood or tissues at the time.

NOTE

Other terms applied to decompression sickness include the bends, compressed-air illness, and caisson disease. Aviators' bends are sometimes called aeroembolism; do not confuse this with *air embolism*, a different condition.

(2) When a diver speaks of *decompression*, he means not only the reduction of pressure that takes place on ascent but also the systematic procedure used to eliminate the excess of dissolved gas safely (by making decompression stops on ascent according to the decompression table).

Cause

(3) Decompression sickness is caused by *inadequate decompression* following a dive, but this does not necessarily mean that the decompression table has not been followed properly. An excessive amount of gas in the tissues can result from any condition (in the man or in the surroundings) that causes an unexpectedly large amount of inert gas to be taken up at depth or that results in abnormally slow elimination of gas during the decompression procedure. In such situations, following the table to the letter does not always assure adequate decompression. However, the decompression tables are designed to cover all but exceptional cases of this sort, so the actual risk of decompression sickness is small if the right table is properly employed.

Prevention

(4) The prevention of decompression sickness is best accomplished by observing these rules:

(*a*) *Careful selection of personnel.*—For example, old injuries or diseases which result in poor circulation are cause for rejection.

(*b*) *Observation and evaluation of each man before he makes any dive.*—Alcohol intoxication or hangover, excessive fatigue, or a general rundown condition are sufficient causes to restrict a man from diving. It is the duty of the diving officer and the diving supervisor to keep any man from diving on a day when his physical condition is not satisfactory. If any doubt exists as to the diver's physical fitness, the medical officer's recommendation will normally be the deciding factor. Divers have a responsibility for keeping themselves fit to the best of their ability.

(*c*) *Careful attention to the details of the dive.*—Accurate determination of the depth and time of the dive and of the decompression time must be made (1.4.7(15)). All data concerning these details must be accurately and completely recorded and kept readily available. They are important in the diagnosis and treatment of decompression sickness.

(*d*) *Strict observance of the decompression tables, with due consideration of modifying factors.*—Follow the tables at all times unless there is reason to question the accuracy of depth or time. In this event, decompress the diver for a dive of greater depth or longer duration. When in doubt, always act in the diver's favor by adding to the decompression time. Never shorten a decompression table merely for convenience.

(*e*) *Report all symptoms or signs immediately to the medical or diving officer.*—Serious cases of decompression sickness often begin with a slight itch or pain. When men fail to report early symptoms, their chances of suffering permanent damage are greatly increased, and their treatment is likely to be much more prolonged.

Diagnosis

(5) Diagnosis of decompression sickness depends upon the evaluation of the history of the dive, the symptoms and signs of the patient, and your ability to do a simple physical examination.

Case History

(6) Decompression sickness is usually associated with diving, but can also be associated with caisson work, aviation, environmental chambers,

etc. Symptoms which occur 24 hours or more following a dive are probably not decompression sickness. The fact that a dive was of short duration, that it was at a relatively shallow depth, or that the decompression table was followed does not necessarily rule out the possibility of decompression sickness. As a general rule, however, as the depth, time, and severity of work increases, the frequency of decompression sickness also increases. The likelihood increases very much when a diver does not receive proper decompression.

Symptoms and Signs

(7) Decompression sickness usually causes symptoms within a short period of time following a dive. If a diver comes quickly to the surface without the required stops, or if he makes stops of greatly insufficient duration, he may be suffering from decompression sickness when he reaches the surface. Most cases develop after a short period of time on the surface and almost always before 12 hours. A review of data concerning the onset of symptoms following decompression revealed that—

50 percent occurred within 30 minutes
85 percent occurred within 1 hour
95 percent occurred within 3 hours
1 percent delayed over 6 hours

(8) Various symptoms of decompression sickness have been found to occur with the following frequency:

	Percent
Local pain	89
Leg	30
Arm	70
Dizziness (the staggers)	5.3
Paralysis	2.3
Shortness of breath (the chokes)	1.6
Extreme fatigue and pain	1.3
Collapse with unconsciousness	.5

(9) Occasionally the skin may show a blotchy and mottled rash. There may be small red spots that vary in size from a pinhead to the size of a dime. Sometimes mottling is so pronounced that the skin takes on an appearance like that of pink marble, and the term "marbling" is applied.

(10) A typical case of decompression sickness may begin with itching or burning of a localized area of the body. This symptom may spread and then finally become localized again. There may be a feeling of tingling or numbness of the skin. In rare cases, the man may have a sensation of ants crawling over him.

(11) Pain, which is the most frequent and predominating symptom, is of a deep and boring character. Divers describe it as being felt in the bone or in the joint. Usually the pain is slight when first noticed and then becomes progressively worse until it is unbearable. The pain usually is not affected by movement of the area, but it may be temporarily relieved by vigorous rubbing or hot applications. The most frequently confused situation is that of a diver suffering a muscle strain or a joint sprain during a dive. However, this condition can usually be distinguished by the fact that strains and sprains are painful to touch and motion, while pain in a joint from decompression sickness is generally not. Swelling and discoloration usually occur with a sprain but are rare in uncomplicated cases of decompression sickness. A diver who has pain that might be a symptom of decompression sickness should have *treatment* by recompression, even though the pain may turn out to have been from a strain or sprain. WHEN IN DOUBT, TREAT BY RECOMPRESSION. Failure to treat doubtful cases is the most frequent cause of lasting injury.

(12) Abdominal pain after a dive has frequently been followed by symptoms and signs of spinal cord involvement (i.e., weakness or paralysis of legs; burning, tingling, or numbness of legs or feet). It is important to recognize that the onset of abdominal pain in decompression sickness is a serious symptom requiring immediate recompression *treatment* as such. Careful examination of the diver upon his arrival at depth in the chamber should determine the extent of spinal cord involvement and the time necessary for complete resolution of the involvement in order to select the proper table for treatment.

(13) When dizziness occurs, the diver feels that the world is revolving about him and that he is falling to one side. Frequently, he will have ringing in the ears at the same time that dizziness occurs. History and physical examination become important when these symptoms

occur because they also can follow middle-ear damage as from squeeze.

(8) Serious symptoms are those caused by bubbles in the brain, spinal cord, or lungs. These symptoms require longer treatment (tables 1–3 and 1–4) than the pain-only type, and it is very important not to overlook them when they are present. Many of the serious symptoms are so well defined that the diver is certain to notice and report the symptoms, or the signs are so obvious that his tenders cannot miss them. However, it is quite possible to miss some of the less obvious signs and symptoms or to fail to recognize the milder disorders such as simple weakness, partial paralysis, or defective vision. Do not let a serious case be treated inadequately simply because no one bothered to check! For example, occasionally a diver who complains only of pain in an arm or a leg will also be found to have weakness or partial paralysis when he is examined thoroughly. It is also important to know *all* that is wrong with the patient so that you can be sure he is relieved of all his symptoms during *treatment*.

FIGURE 1–34.—Medical officer examining diver in recompression chamber. It is extremely important to detect any abnormal sign or symptom a diver may have as a result of decompression sickness.

FIGURE 1–35.—Diver breathing oxygen during treatment of decompression sickness. Use of oxygen hastens elimination of nitrogen and greatly shortens treatment. Because there is a slight chance that patient may develop oxygen poisoning, he must be tended carefully while breathing oxygen.

(9) If a medical officer is present, it is his responsibility to examine the man (figs. 1–34 and 1–35). If there is no medical officer, this examination becomes the responsibility of the corpsman, diving officer, or diving supervisor.

(a) If the diver reports only pain and is not suffering severely, examine him thoroughly at the surface.

(b) If it is clear that serious symptoms are present, do not take time for a complete examination of the diver at the surface. You know the man needs *treatment* from Treatment Table 2, 4, or 6 (tables 1–3 and 1–5), and the best procedure is to take him to pressure in the chamber without delay. Once treatment depth is reached, proceed with the best examination you know how to perform (fig. 1–35).

(10) The following are the most important things to check when examining a man prior to treatment or when trying to determine whether all symptoms have been relieved:

(a) *How does he feel?* (Ask him.)

1. Pain—where and how severe? Changed by motion? Sore to touch or pressure? Bruise marks in the area?

2. Mentally clear?

etc. Symptoms which occur 24 hours or more following a dive are probably not decompression sickness. The fact that a dive was of short duration, that it was at a relatively shallow depth, or that the decompression table was followed does not necessarily rule out the possibility of decompression sickness. As a general rule, however, as the depth, time, and severity of work increases, the frequency of decompression sickness also increases. The likelihood increases very much when a diver does not receive proper decompression.

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(12) Abdominal pain after a dive has frequently been followed by symptoms and signs of spinal cord involvement (i.e., weakness or paralysis of legs; burning, tingling, or numbness of legs or feet). It is important to recognize that the onset of abdominal pain in decompression sickness is a serious symptom requiring immediate recompression *treatment* as such. Careful examination of the diver upon his arrival at depth in the chamber should determine the extent of spinal cord involvement and the time necessary for complete resolution of the involvement in order to select the proper table for treatment.

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occur because they also can follow middle-ear damage, as from squeeze.

(14) Serious symptoms are those caused by bubbles in the brain, spinal cord, or lungs. These symptoms require longer *treatment* (tables 1–30 and 1–31) than the pain-only type, and it is very important not to overlook them when they are present. Many of the serious symptoms are so well defined that the diver is certain to notice and report the symptoms, or the signs are so obvious that his tenders cannot miss them. However, it is quite possible to miss some of the less obvious signs and symptoms or to fail to recognize the milder disorders such as simple weakness, partial paralysis, or defective vision. Do not let a serious case be treated inadequately simply because no one bothered to check! For example, occasionally a diver who complains only of pain in an arm or a leg will also be found to have weakness or partial paralysis when he is examined thoroughly. It is also important to know *all* that is wrong with the patient so that you can be sure he is relieved of all his symptoms during *treatment.*

FIGURE 1–34.—Medical officer examining diver in recompression chamber. It is extremely important to detect any abnormal sign or symptom a diver may have as a result of decompression sickness.

FIGURE 1–35.—Diver breathing oxygen during treatment of decompression sickness. Use of oxygen hastens elimination of nitrogen and greatly shortens treatment. Because there is a slight chance that patient may develop oxygen poisoning, he must be tended carefully while breathing oxygen.

(15) If a medical officer is present, it is his responsibility to examine the man (figs. 1–34 and 1–35). If there is no medical officer, this examination becomes the responsibility of the corpsman, diving officer, or diving supervisor.

(*a*) If the diver reports only pain and is not suffering severely, examine him thoroughly at the surface.

(*b*) If it is clear that serious symptoms are present, do not take time for a complete examination of the diver at the surface. You know the man needs *treatment* from Treatment Table 3, 4, or 6 (tables 1–30 and 1–31), and the best procedure is to take him to pressure in the chamber without delay. Once treatment depth is reached, proceed with the best examination you know how to perform (fig. 1–35).

(16) The following are the most important things to check when examining a man prior to treatment or when trying to determine whether all symptoms have been relieved:

(*a*) *How does he feel?* (Ask him.)

1. Pain—where and how severe? Changed by motion? Sore to touch or pressure? Bruise marks in the area?

2. Mentally clear?

370–711 O—70——13

3. Weakness, numbness, or peculiar sensations anywhere?

4. Can he see and hear clearly?

5. Can he walk, talk, and use his hands normally?

6. Any dizziness?

(*b*) *Does he look and act normal?* (Don't merely take his word if he says that he is all right.)

1. Can he walk normally? Any limping or staggering?

2. Is his speech clear and sensible?

3. Is he clumsy or does he seem to be having difficulty with any act of movement?

4. Can he keep his balance when standing with his eyes closed?

(*c*) *Does he have normal strength?* (Check his strength against your own and compare his right side with his left.)

1. Normal handgrip?

2. Able to push and pull strongly with both arms and legs?

3. Able to do deep knee bends and other exercises?

(*d*) *Are his sensations normal?*

1. Can he hear clearly?

2. Can he see clearly both close (reading) and distant objects? Normal vision in all directions?

3. Can he feel pinpricks and light touches with a wisp of cotton all over his body? (Note that some areas are normally less sensitive than others—compare with yourself if in doubt.)

(*e*) *Look at his eyes:*

1. Are the pupils normal size and equal?

2. Do they close down when you shine a light in his eyes?

3. Can he follow an object around normally with his eyes?

(*f*) *Check his reflexes* if you know how.

(17) Note that it should not take a great deal of time to examine a man reasonably well. Especially when you are under pressure in the chamber, there is seldom time to waste; but do not shortchange the patient. If there is real need for haste, having him walk and do a few exercises will usually show (or call to his attention) the more serious defects.

(18) In all cases where there is any doubt, treat the diver as though he is suffering from decompression sickness. If you are not sure that he is completely free from *serious* symptoms, use the longer table. Remember that time and air are much cheaper than joints and brain tissue.

(FORMERLY TABLE 1-20, 1963 DIVING MANUAL)

TABLE 1-29.—*Treatment of an unconscious diver*

(Loss of consciousness during, or within 24 hours after, a dive. See 1.6.4)

1. If the diver is not breathing, start mouth-to-mouth or manual artificial respiration at once (see app. A).
2. Recompress promptly (see note *d*).
3. Examine for injuries and other abnormalities; apply first aid and other measures as required. (Secure the help of a medical officer as soon as possible.)

Notes

Artificial respiration:

a. Shift to a mechanical resuscitator if one is available and working properly, but never wait for it. Always start the mouth-to-mouth or manual methods first.

b. Continue artificial respiration by some method without interruption until normal breathing resumes or the victim is pronounced dead. Continue on the way to the chamber and during recompression. (Do not use oxygen deeper than 60 feet in the chamber.)

Recompression:

c. Remember that an unconscious diver may have air embolism or serious decompression sickness even though some other accident seems to explain his condition.

d. Recompress unless—

1. The victim regains consciousness and is free of nervous system symptoms before recompression can be started.
2. The possibility of air embolism or decompression sickness can be ruled out without question.
3. Another lifesaving measure is absolutely required and makes recompression impossible.

e. Try to reach a recompression chamber no matter how far it is.

f. Treat according to the treatment tables (see tables 1-30 and 1-31), depending on response. Remember that early recovery under pressure never rules out the need for adequate treatment.

(FORMERLY TABLE 1-21, 1963 DIVING MANUAL)

TABLE 1-30.—*Treatment of decompression sickness and air embolism*

Stops		Bends—pain only				Serious symptoms	
Rate of descent—25 feet per minute. Rate of ascent—1 minute between stops.		Pain relieved at depths less than 66 feet. Use table 1A if O_2 is not available......		Pain relieved at depths greater than 66 feet. Use table 2A if O_2 is not available...... If pain does not improve within 30 minutes at 165 feet, the case is probably not bends. Decompress on table 2 or 2A.		Serious symptoms include any one of the following: 1. Unconsciousness. 2. Convulsions. 3. Weakness or inability to use arms or legs. 4. Air embolism. 5. Any visual disturbances. 6. Dizziness. 7. Loss of speech or hearing. 8. Severe shortness of breath or chokes. 9. Bends occurring while still under pressure.	
						Symptoms relieved within 30 minutes at 165 feet. Use table 3	Symptoms not relieved within 30 minutes at 165 feet. Use table 4
Pounds	**Feet**	**Table 1**	**Table 1A**	**Table 2**	**Table 2A**	**Table 3**	**Table 4**
73.4	165	....	....	30 (air)	30 (air)	30 (air)	30 to 120 (air)
62.3	140	....	....	12 (air)	12 (air)	12 (air)	30 (air)
53.4	120	....	....	12 (air)	12 (air)	12 (air)	30 (air)
44.5	100	30 (air)	30 (air)	12 (air)	12 (air)	12 (air)	30 (air)
35.6	80	12 (air)	12 (air)	12 (air)	12 (air)	12 (air)	30 (air)
26.7	60	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
22.3	50	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
17.8	40	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
13.4	30		60 (air)	60 (O_2)	2 hr (air)	12 hr (air)	First 11 hr (air) Then 1 hr (O_2) or (air)
8.9	20	5 (O_2)	60 (air)		2 hr (air)	2 hr (air)	First 1 hr (air) Then 1 hr (O_2) or (air)
				5 (O_2)			
4.5	10		2 hr (air)		4 hr (air)	2 hr (air)	First 1 hr (air) Then 1 hr (O_2) or (air)
Surface			1 min (air)		1 min (air)	1 min (air)	1 min (O_2)

Time at all stops in minutes unless otherwise indicated.

TABLE 1-31.—*Minimal recompression, oxygen breathing method for treatment of decompression sickness and air embolism*

Stops	Bends—pain only			Serious symptoms and air embolism								
(a)	Pain relieved within 10 minutes at 60 feet. If any pain persists after 10 minutes at 60 feet, use table 6.			Pain relieved after 10 minutes at 60 feet. Serious symptoms include any one of the following: 1. Unconsciousness. 2. Nervous system symptoms. 3. Bends under pressure.			Treatment of air embolism. Rate of descent is as fast as possible. Use this table if all symptoms are gone within 15 minutes and proceed to 60 feet when relief is complete.			Treatment of air embolism if symptoms moderate to a major extent within 30 minutes at 60 feet. If symptoms persist, use table 4.		
	Table 5 [b]			Table 6 [b]			Table 5A [c]			Table 6A [c]		
Depth (feet)	Time (minutes)	Breathing media	Total elapsed time (minutes)	Time (minutes)	Breathing media	Total elapsed time (minutes)	Time (minutes)	Breathing media	Total elasped time (minutes)	Time (minutes)	Breathing media	Total elapsed time (minutes)
165	...	...	...	...	...	...	[d] 15	Air	15	30	Air	30
165 to 60	...	...	...	...	...	...	4	Air	19	4	Air	34
60	...	...	...	20	Oxygen	20	...	...	...	20	Oxygen	54
60	...	...	...	5	Air	25	...	...	...	5	Air	59
60	...	...	...	20	Oxygen	45	...	...	...	20	Oxygen	79
60	20	Oxgyen	20	5	Air	50	20	Oxygen	39	5	Air	84
60	5	Air	25	20	Oxygen	70	5	Air	44	20	Oxygen	104
60	20	Oxygen	45	5	Air	75	20	Oxygen	64	5	Air	109
60 to 30	30	Oxygen	75	30	Oxygen	105	30	Oxygen	94	30	Oxygen	139
30	...	...	...	15	Air	120	...	...	...	15	Air	154
30	5	Air	80	60	Oxygen	180	5	Air	99	60	Oxygen	214
30	20	Oxygen	100	15	Air	195	20	Oxygen	119	15	Air	229
30	5	Air	105	60	Oxygen	255	5	Air	124	60	Oxygen	289
30 to 0	30	Oxygen	135	30	Oxygen	285	30	Oxygen	154	30	Oxygen	319

[a] The rate of ascent is 1 foot per minute. Do not compensate for slowing of the rate by subsequent acceleration. Do compensate if the rate is exceeded. If necessary, halt ascent and hold depth while ventilating the chamber.

[b] The time at 60 feet begins on arrival at 60 feet. The patient should be on oxgyen from the surface.

[c] The time at 165 feet is total bottom time and includes the time from the surface.

[d] Total time will vary as a function of this stop. The medical attendant should take enough time to accomplish a thorough physical examination, because the ensuing treatment is based on the patient's physical status.

(FORMERLY TABLE 1-22, 1963 DIVING MANUAL)

TABLE 1-32.—*Notes on recompression*

1. General considerations:
   a. Follow the treatment tables (table 1-30 or 1-31) accurately.
   b. Permit no shortening or other alterations of the tables except on the advice of a trained diving medical officer or in an extreme emergency.
2. Rate of descent in the chamber:
   a. The normal descent rate is 25 feet per minute.
   b. If serious symptoms are present: rapid descent is desirable.
   c. If pain increases on descent: stop, resume at a rate tolerated by the patient.
3. Treatment depth:
   a. Go to the full depth indicated by the table required.
   b. Do not go beyond 165 feet except on the decision of a medical officer who has been trained in diving.
4. Examination of the patient (see 1.6.2):
   a. If no serious symptoms are evident and pain is not severe, examine the patient thoroughly before treatment.
   b. If any serious symptom is noted, do not delay recompression for examination or for determining depth of relief.
   c. If Treatment Tables 5, 6, 5A, or 6A are used, a medical officer must be present and a qualified medical attendant must always accompany the patient in the chamber during treatment.
   d. In "pain only" cases, make sure that relief is complete within 10 minutes at 60 feet on oxygen if table 5 is used. If not, table 6 may be used. If table 1 is used, make sure that complete relief has been reported before reaching 66 feet.
   e. On reaching treatment depth, examine the patient as completely as possible to detect—
      1. Incomplete relief.
      2. Any symptoms overlooked.

NOTE

At the very least, have the patient stand and walk the length of the chamber if this is at all possible.

   f. Recheck the patient before leaving the treatment depth.
   g. Ask the patient how he feels before and after coming to each stop and periodically during long stops.
   h. Do not let the patient sleep through changes of depth or for more than an hour at a time at any stop. (Symptoms can develop or recur during sleep.)
   i. Recheck the patient before leaving the last stop.
   j. During treatment make sure that the patient can obtain all the things that he needs, such as food, liquids, and any other items that he might require.
5. Patient getting worse:
   a. Never continue ascent if the patient's condition is worsening.
   b. Treat the patient as a recurrence during treatment (see 6).
   c. Consider the use of helium-oxygen as a breathing medium for the patient (see 8).
6. Recurrence of symptoms:
   a. During treatment:
      1. Recompress to depth of relief (but never less than 30 feet or deeper than 165 feet except on decision of a medical officer).
      2. If a medical officer is available and the depth of relief is less than 60 feet, recompress to 60 feet and treat on table 6.
      3. If a medical officer is not available or the depth of relief is greater than 60 feet, complete the treatment according to table 4; i.e., remain at depth of relief for 30 minutes and complete remaining stops of table 4.
      4. If recurrence involves serious symptoms not previously present, take the patient to 60 feet and treat on table 6 or take the patient to 165 feet and treat on table 4.
   b. Following treatment:
      1. Recompress to 60 feet and use table 6 if a medical officer is available.
      2. If the depth of relief is less than 30-feet, recompress the patient to 30 feet and decompress from the 30-foot stop according to table 3.
      3. If the depth of relief is deeper than 30 feet, keep the patient at depth of relief for 30 minutes and decompress according to table 3.

(FORMERLY TABLE 1–19, 1963 DIVING MANUAL)

TABLE 1–28.—*Oxygen depth-time limits*

[Depth and time limits of exposure for breathing pure oxygen during working dives]

1. Normal oxygen limits—*Do not dive deeper than 25 feet.* Observe these time limits:

Depth (ft)	Time (min)
10	240
15	150
20	110
25	75

2. Limits for exceptional operations:

Depth (ft)	Time (min)
30	45
35	25
40	10

3. Emergency limits. (See art. 1.5.7, par. (7), and fig. 1–33.)

Emergency Limit

(7) Extraordinary situations, such as the requirement for an extremely important mission when oxygen is the only breathing medium that can be used, might dictate that an attempt be made to exceed the limits of table 1–28. These paragraphs present the odds for and against success.

(8) Figure 1–33 shows the results of experimental exposures to pure oxygen at various depths for various times. The proximity of possible warning symptoms and even convulsions to the Important Operation Limit Curve is apparent. Less apparent is the contrast between the perfect conditions that existed during these exposures and the conditions that would probably exist in the field. The experiments were conducted in a pressure tank; the work rates were moderate and uniform; the inspired gas was free of carbon dioxide; and two tenders were standing by each subject. It is likely that exposure to oxygen at these depths for the same times under operating conditions would produce a much larger proportion of unfavorable effects.

(9) The necessity to exceed the limits of table 1–28 in order to accomplish a mission must be brought to the attention of the officer assigning the mission, who must accept the responsibility for the increased hazard to personnel.

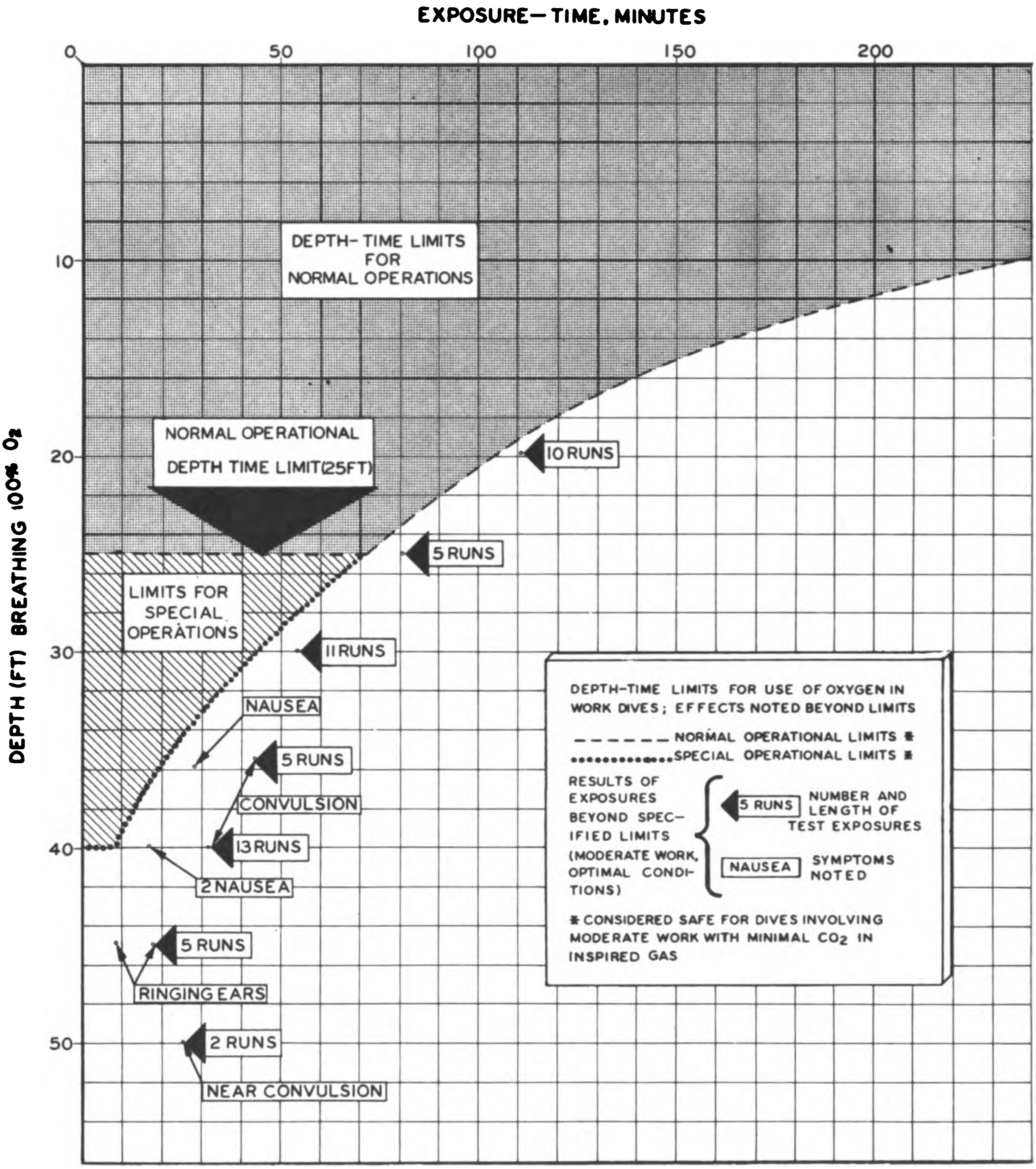

FIGURE 1–33.—Oxygen depth-time limits.

SECTION 1.6 DIVING HAZARDS

1.6.1 INTRODUCTION

General

(1) Diving confronts man with forces and physiological effects that are not encountered in his normal environment. These forces impose definite limits and can cause serious accidents. The diver's safety depends upon his knowledge of these factors and his ability to recognize and handle them.

Recognition and Management of Hazards

(2) The discussions on physics and physiology have made you aware of most of the potential hazards of diving. The purpose of this chapter is to give you knowledge which will help you to avoid hazards whenever possible, to cope with hazards which cannot be avoided, and to recognize and treat accidents when they occur. It permits you to evaluate the factors of environment, of specific equipment, and of your own condition in relation to each job. *Ignorance is the diver's worst enemy.* Many potential dangers can almost completely be avoided if they are recognized. To cite one example, many amateur divers would be alive today if they had known that holding their breath on ascent would cause air embolism. Even after such an accident occurred, many of these lives could have been saved if anyone nearby had recognized the condition and had been able to provide proper treatment.

(3) You will meet with many unavoidable hazards, but awareness and understanding will permit you to face them with a minimum of risk. Under combat conditions, some of these hazards are likely to be increased and diving must be performed under conditions which would be otherwise unacceptable.

(4) When a dangerous condition is developing in yourself, your buddy, or the man you are tending or supervising, active *awareness* promotes early recognition of danger and enables you to take immediate corrective action. As a diver, you must know the *causes*, *symptoms*, and *signs* of diving accidents so that proper actions or treatment can be commenced without delay.

(5) In the following discussions of accidents, the words *symptom* and *sign* will be used frequently. The following explanation is given to clarify their meanings as used in this manual: *Symptom* refers to those sensations experienced by the diver. *Sign* refers to those changes which can be observed by another person. A symptom can also be a sign. For example, a diver may complain of an inability to move his leg. This is a symptom. The observer might see limping or the inability to lift that leg. These are signs. Pain is purely a symptom, because the observer cannot feel or see it. He may see evidence of it, such as wincing or grimacing, but the observer cannot determine the existence of a symptom such as pain other than by the report of the patient. This differentiation between signs and symptoms adds to the awareness of the diver. Such awareness becomes particularly important in the use of scuba, because the individual and his buddy must protect not only themselves but also each other. The diver must be able to recognize *symptoms* in himself and must also be able to recognize *signs* of early stages of accidents in his buddy so that prompt corrective action may be taken.

(6) When a hazard is encountered or an accident occurs, you must take all possible action to prevent further development of the condition. You must know the proper treatment of a condition which has already developed. In order to accomplish treatment, you must be familiar with the proper operation of such specialized equipment as recompression chambers and resuscitators. In addition, knowledge of manual artificial-respiration methods and first-aid principles must be a part of your ability to cope with diving accidents. You must know how to trans-

port casualties properly, taking into consideration problems of pressure and good first-aid technique.

1.6.2 DECOMPRESSION SICKNESS

(1) As previously discussed, decompression sickness is the result of the formation of gas bubbles in the blood or tissues. Decompression sickness can occur only when decompression (a reduction in the pressure surrounding the body) has taken place—as when a diver comes up from depth or when an aviator goes up to high altitude. Decompression sickness will not occur unless there is an excessive amount of inert gas dissolved in the blood or tissues at the time.

NOTE

Other terms applied to decompression sickness include the bends, compressed-air illness, and caisson disease. Aviators' bends are sometimes called aeroembolism; do not confuse this with *air embolism*, a different condition.

(2) When a diver speaks of *decompression*, he means not only the reduction of pressure that takes place on ascent but also the systematic procedure used to eliminate the excess of dissolved gas safely (by making decompression stops on ascent according to the decompression table).

Cause

(3) Decompression sickness is caused by *inadequate decompression* following a dive, but this does not necessarily mean that the decompression table has not been followed properly. An excessive amount of gas in the tissues can result from any condition (in the man or in the surroundings) that causes an unexpectedly large amount of inert gas to be taken up at depth or that results in abnormally slow elimination of gas during the decompression procedure. In such situations, following the table to the letter does not always assure adequate decompression. However, the decompression tables are designed to cover all but exceptional cases of this sort, so the actual risk of decompression sickness is small if the right table is properly employed.

Prevention

(4) The prevention of decompression sickness is best accomplished by observing these rules:

(*a*) *Careful selection of personnel.*—For example, old injuries or diseases which result in poor circulation are cause for rejection.

(*b*) *Observation and evaluation of each man before he makes any dive.*—Alcohol intoxication or hangover, excessive fatigue, or a general rundown condition are sufficient causes to restrict a man from diving. It is the duty of the diving officer and the diving supervisor to keep any man from diving on a day when his physical condition is not satisfactory. If any doubt exists as to the diver's physical fitness, the medical officer's recommendation will normally be the deciding factor. Divers have a responsibility for keeping themselves fit to the best of their ability.

(*c*) *Careful attention to the details of the dive.*—Accurate determination of the depth and time of the dive and of the decompression time must be made (1.4.7(15)). All data concerning these details must be accurately and completely recorded and kept readily available. They are important in the diagnosis and treatment of decompression sickness.

(*d*) *Strict observance of the decompression tables, with due consideration of modifying factors.*—Follow the tables at all times unless there is reason to question the accuracy of depth or time. In this event, decompress the diver for a dive of greater depth or longer duration. When in doubt, always act in the diver's favor by adding to the decompression time. Never shorten a decompression table merely for convenience.

(*e*) *Report all symptoms or signs immediately to the medical or diving officer.*—Serious cases of decompression sickness often begin with a slight itch or pain. When men fail to report early symptoms, their chances of suffering permanent damage are greatly increased, and their treatment is likely to be much more prolonged.

Diagnosis

(5) Diagnosis of decompression sickness depends upon the evaluation of the history of the dive, the symptoms and signs of the patient, and your ability to do a simple physical examination.

Case History

(6) Decompression sickness is usually associated with diving, but can also be associated with caisson work, aviation, environmental chambers,

etc. Symptoms which occur 24 hours or more following a dive are probably not decompression sickness. The fact that a dive was of short duration, that it was at a relatively shallow depth, or that the decompression table was followed does not necessarily rule out the possibility of decompression sickness. As a general rule, however, as the depth, time, and severity of work increases, the frequency of decompression sickness also increases. The likelihood increases very much when a diver does not receive proper decompression.

Symptoms and Signs

(7) Decompression sickness usually causes symptoms within a short period of time following a dive. If a diver comes quickly to the surface without the required stops, or if he makes stops of greatly insufficient duration, he may be suffering from decompression sickness when he reaches the surface. Most cases develop after a short period of time on the surface and almost always before 12 hours. A review of data concerning the onset of symptoms following decompression revealed that—

50 percent occurred within 30 minutes
85 percent occurred within 1 hour
95 percent occurred within 3 hours
1 percent delayed over 6 hours

(8) Various symptoms of decompression sickness have been found to occur with the following frequency:

	Percent
Local pain	89
Leg	30
Arm	70
Dizziness (the staggers)	5.3
Paralysis	2.3
Shortness of breath (the chokes)	1.6
Extreme fatigue and pain	1.3
Collapse with unconsciousness	.5

(9) Occasionally the skin may show a blotchy and mottled rash. There may be small red spots that vary in size from a pinhead to the size of a dime. Sometimes mottling is so pronounced that the skin takes on an appearance like that of pink marble, and the term "marbling" is applied.

(10) A typical case of decompression sickness may begin with itching or burning of a localized area of the body. This symptom may spread and then finally become localized again. There may be a feeling of tingling or numbness of the skin. In rare cases, the man may have a sensation of ants crawling over him.

(11) Pain, which is the most frequent and predominating symptom, is of a deep and boring character. Divers describe it as being felt in the bone or in the joint. Usually the pain is slight when first noticed and then becomes progressively worse until it is unbearable. The pain usually is not affected by movement of the area, but it may be temporarily relieved by vigorous rubbing or hot applications. The most frequently confused situation is that of a diver suffering a muscle strain or a joint sprain during a dive. However, this condition can usually be distinguished by the fact that strains and sprains are painful to touch and motion, while pain in a joint from decompression sickness is generally not. Swelling and discoloration usually occur with a sprain but are rare in uncomplicated cases of decompression sickness. A diver who has pain that might be a symptom of decompression sickness should have *treatment* by recompression, even though the pain may turn out to have been from a strain or sprain. WHEN IN DOUBT, TREAT BY RECOMPRESSION. Failure to treat doubtful cases is the most frequent cause of lasting injury.

(12) Abdominal pain after a dive has frequently been followed by symptoms and signs of spinal cord involvement (i.e., weakness or paralysis of legs; burning, tingling, or numbness of legs or feet). It is important to recognize that the onset of abdominal pain in decompression sickness is a serious symptom requiring immediate recompression *treatment* as such. Careful examination of the diver upon his arrival at depth in the chamber should determine the extent of spinal cord involvement and the time necessary for complete resolution of the involvement in order to select the proper table for treatment.

(13) When dizziness occurs, the diver feels that the world is revolving about him and that he is falling to one side. Frequently, he will have ringing in the ears at the same time that dizziness occurs. History and physical examination become important when these symptoms

occur because they also can follow middle-ear damage, as from squeeze.

(14) Serious symptoms are those caused by bubbles in the brain, spinal cord, or lungs. These symptoms require longer *treatment* (tables 1–30 and 1–31) than the pain-only type, and it is very important not to overlook them when they are present. Many of the serious symptoms are so well defined that the diver is certain to notice and report the symptoms, or the signs are so obvious that his tenders cannot miss them. However, it is quite possible to miss some of the less obvious signs and symptoms or to fail to recognize the milder disorders such as simple weakness, partial paralysis, or defective vision. Do not let a serious case be treated inadequately simply because no one bothered to check! For example, occasionally a diver who complains only of pain in an arm or a leg will also be found to have weakness or partial paralysis when he is examined thoroughly. It is also important to know *all* that is wrong with the patient so that you can be sure he is relieved of all his symptoms during *treatment*.

FIGURE 1–34.—Medical officer examining diver in recompression chamber. It is extremely important to detect any abnormal sign or symptom a diver may have as a result of decompression sickness.

FIGURE 1–35.—Diver breathing oxygen during treatment of decompression sickness. Use of oxygen hastens elimination of nitrogen and greatly shortens treatment. Because there is a slight chance that patient may develop oxygen poisoning, he must be tended carefully while breathing oxygen.

(15) If a medical officer is present, it is his responsibility to examine the man (figs. 1–34 and 1–35). If there is no medical officer, this examination becomes the responsibility of the corpsman, diving officer, or diving supervisor.

(*a*) If the diver reports only pain and is not suffering severely, examine him thoroughly at the surface.

(*b*) If it is clear that serious symptoms are present, do not take time for a complete examination of the diver at the surface. You know the man needs *treatment* from Treatment Table 3, 4, or 6 (tables 1–30 and 1–31), and the best procedure is to take him to pressure in the chamber without delay. Once treatment depth is reached, proceed with the best examination you know how to perform (fig. 1–35).

(16) The following are the most important things to check when examining a man prior to treatment or when trying to determine whether all symptoms have been relieved:

(*a*) *How does he feel?* (Ask him.)

1. Pain—where and how severe? Changed by motion? Sore to touch or pressure? Bruise marks in the area?

2. Mentally clear?

3. Weakness, numbness, or peculiar sensations anywhere?

4. Can he see and hear clearly?

5. Can he walk, talk, and use his hands normally?

6. Any dizziness?

(*b*) *Does he look and act normal?* (Don't merely take his word if he says that he is all right.)

1. Can he walk normally? Any limping or staggering?

2. Is his speech clear and sensible?

3. Is he clumsy or does he seem to be having difficulty with any act of movement?

4. Can he keep his balance when standing with his eyes closed?

(*c*) *Does he have normal strength?* (Check his strength against your own and compare his right side with his left.)

1. Normal handgrip?

2. Able to push and pull strongly with both arms and legs?

3. Able to do deep knee bends and other exercises?

(*d*) *Are his sensations normal?*

1. Can he hear clearly?

2. Can he see clearly both close (reading) and distant objects? Normal vision in all directions?

3. Can he feel pinpricks and light touches with a wisp of cotton all over his body? (Note that some areas are normally less sensitive than others—compare with yourself if in doubt.)

(*e*) *Look at his eyes:*

1. Are the pupils normal size and equal?

2. Do they close down when you shine a light in his eyes?

3. Can he follow an object around normally with his eyes?

(*f*) *Check his reflexes* if you know how.

(17) Note that it should not take a great deal of time to examine a man reasonably well. Especially when you are under pressure in the chamber, there is seldom time to waste; but do not shortchange the patient. If there is real need for haste, having him walk and do a few exercises will usually show (or call to his attention) the more serious defects.

(18) In all cases where there is any doubt, treat the diver as though he is suffering from decompression sickness. If you are not sure that he is completely free from *serious* symptoms, use the longer table. Remember that time and air are much cheaper than joints and brain tissue.

(FORMERLY TABLE 1–20, 1963 DIVING MANUAL)

TABLE 1–29.—*Treatment of an unconscious diver*

(Loss of consciousness during, or within 24 hours after, a dive. See 1.6.4)

1. If the diver is not breathing, start mouth-to-mouth or manual artificial respiration at once (see app. A).
2. Recompress promptly (see note *d*).
3. Examine for injuries and other abnormalities; apply first aid and other measures as required. (Secure the help of a medical officer as soon as possible.)

Notes

Artificial respiration:

a. Shift to a mechanical resuscitator if one is available and working properly, but never wait for it. Always start the mouth-to-mouth or manual methods first.

b. Continue artificial respiration by some method without interruption until normal breathing resumes or the victim is pronounced dead. Continue on the way to the chamber and during recompression. (Do not use oxygen deeper than 60 feet in the chamber.)

Recompression:

c. Remember that an unconscious diver may have air embolism or serious decompression sickness even though some other accident seems to explain his condition.

d. Recompress unless—

1. The victim regains consciousness and is free of nervous system symptoms before recompression can be started.
2. The possibility of air embolism or decompression sickness can be ruled out without question.
3. Another lifesaving measure is absolutely required and makes recompression impossible.

e. Try to reach a recompression chamber no matter how far it is.

f. Treat according to the treatment tables (see tables 1–30 and 1–31), depending on response. Remember that early recovery under pressure never rules out the need for adequate treatment.

(FORMERLY TABLE 1-21, 1963 DIVING MANUAL)

TABLE 1-30.—*Treatment of decompression sickness and air embolism*

Stops	Bends—pain only		Serious symptoms	
Rate of descent—25 feet per minute. Rate of ascent—1 minute between stops.	Pain relieved at depths less than 66 feet. Use table 1A if O_2 is not available......	Pain relieved at depths greater than 66 feet. Use table 2A if O_2 is not available...... If pain does not improve within 30 minutes at 165 feet, the case is probably not bends. Decompress on table 2 or 2A.	Serious symptoms include any one of the following: 1. Unconsciousness. 2. Convulsions. 3. Weakness or inability to use arms or legs. 4. Air embolism. 5. Any visual disturbances. 6. Dizziness. 7. Loss of speech or hearing. 8. Severe shortness of breath or chokes. 9. Bends occurring while still under pressure.	
			Symptoms relieved within 30 minutes at 165 feet. Use table 3	Symptoms not relieved within 30 minutes at 165 feet. Use table 4

Pounds	Feet	Table 1	Table 1A	Table 2	Table 2A	Table 3	Table 4
73.4	165	....	....	30 (air)	30 (air)	30 (air)	30 to 120 (air)
62.3	140	....	....	12 (air)	12 (air)	12 (air)	30 (air)
53.4	120	....	....	12 (air)	12 (air)	12 (air)	30 (air)
44.5	100	30 (air)	30 (air)	12 (air)	12 (air)	12 (air)	30 (air)
35.6	80	12 (air)	12 (air)	12 (air)	12 (air)	12 (air)	30 (air)
26.7	60	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
22.3	50	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
17.8	40	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
13.4	30		60 (air)	60 (O_2)	2 hr (air)	12 hr (air)	First 11 hr (air) Then 1 hr (O_2) or (air)
8.9	20	5 (O_2) (30 ft to surface)	60 (air)		2 hr (air)	2 hr (air)	First 1 hr (air) Then 1 hr (O_2) or (air)
4.5	10		2 hr (air)	5 (O_2) (20 ft to surface)	4 hr (air)	2 hr (air)	First 1 hr (air) Then 1 hr (O_2) or (air)
Surface			1 min (air)		1 min (air)	1 min (air)	1 min (O_2)

Time at all stops in minutes unless otherwise indicated.

TABLE 1–31.—*Minimal recompression, oxygen breathing method for treatment of decompression sickness and air embolism*

Stops	Bends—pain only			Serious symptoms and air embolism								
(a)	Pain relieved within 10 minutes at 60 feet. If any pain persists after 10 minutes at 60 feet, use table 6.			Pain relieved after 10 minutes at 60 feet. Serious symptoms include any one of the following: 1. Unconsciousness. 2. Nervous system symptoms. 3. Bends under pressure.			Treatment of air embolism. Rate of descent is as fast as possible. Use this table if all symptoms are gone within 15 minutes and proceed to 60 feet when relief is complete.			Treatment of air embolism if symptoms moderate to a major extent within 30 minutes at 60 feet. If symptoms persist, use table 4.		
	Table 5 [b]			Table 6 [b]			Table 5A [c]			Table 6A [c]		
Depth (feet)	Time (minutes)	Breathing media	Total elapsed time (minutes)	Time (minutes)	Breathing media	Total elapsed time (minutes)	Time (minutes)	Breathing media	Total elasped time (minutes)	Time (minutes)	Breathing media	Total elapsed time (minutes)
165							[d] 15	Air	15	30	Air	30
165 to 60							4	Air	19	4	Air	34
60				20	Oxygen	20				20	Oxygen	54
60				5	Air	25				5	Air	59
60				20	Oxygen	45				20	Oxygen	79
60	20	Oxgyen	20	5	Air	50	20	Oxygen	39	5	Air	84
60	5	Air	25	20	Oxygen	70	5	Air	44	20	Oxygen	104
60	20	Oxygen	45	5	Air	75	20	Oxygen	64	5	Air	109
60 to 30	30	Oxygen	75	30	Oxygen	105	30	Oxygen	94	30	Oxygen	139
30				15	Air	120				15	Air	154
30	5	Air	80	60	Oxygen	180	5	Air	99	60	Oxygen	214
30	20	Oxygen	100	15	Air	195	20	Oxygen	119	15	Air	229
30	5	Air	105	60	Oxygen	255	5	Air	124	60	Oxygen	289
30 to 0	30	Oxygen	135	30	Oxygen	285	30	Oxygen	154	30	Oxygen	319

[a] The rate of ascent is 1 foot per minute. Do not compensate for slowing of the rate by subsequent acceleration. Do compensate if the rate is exceeded. If necessary, halt ascent and hold depth while ventilating the chamber.

[b] The time at 60 feet begins on arrival at 60 feet. The patient should be on oxgyen from the surface.

[c] The time at 165 feet is total bottom time and includes the time from the surface.

[d] Total time will vary as a function of this stop. The medical attendant should take enough time to accomplish a thorough physical examination, because the ensuing treatment is based on the patient's physical status.

(FORMERLY TABLE 1-22, 1963 DIVING MANUAL)

TABLE 1-32.—*Notes on recompression*

1. General considerations:
    a. Follow the treatment tables (table 1-30 or 1-31) accurately.
    b. Permit no shortening or other alterations of the tables except on the advice of a trained diving medical officer or in an extreme emergency.
2. Rate of descent in the chamber:
    a. The normal descent rate is 25 feet per minute.
    b. If serious symptoms are present: rapid descent is desirable.
    c. If pain increases on descent: stop, resume at a rate tolerated by the patient.
3. Treatment depth:
    a. Go to the full depth indicated by the table required.
    b. Do not go beyond 165 feet except on the decision of a medical officer who has been trained in diving.
4. Examination of the patient (see 1.6.2):
    a. If no serious symptoms are evident and pain is not severe, examine the patient thoroughly before treatment.
    b. If any serious symptom is noted, do not delay recompression for examination or for determining depth of relief.
    c. If Treatment Tables 5, 6, 5A, or 6A are used, a medical officer must be present and a qualified medical attendant must always accompany the patient in the chamber during treatment.
    d. In "pain only" cases, make sure that relief is complete within 10 minutes at 60 feet on oxygen if table 5 is used. If not, table 6 may be used. If table 1 is used, make sure that complete relief has been reported before reaching 66 feet.
    e. On reaching treatment depth, examine the patient as completely as possible to detect—
        1. Incomplete relief.
        2. Any symptoms overlooked.

NOTE

At the very least, have the patient stand and walk the length of the chamber if this is at all possible.

    f. Recheck the patient before leaving the treatment depth.
    g. Ask the patient how he feels before and after coming to each stop and periodically during long stops.
    h. Do not let the patient sleep through changes of depth or for more than an hour at a time at any stop. (Symptoms can develop or recur during sleep.)
    i. Recheck the patient before leaving the last stop.
    j. During treatment make sure that the patient can obtain all the things that he needs, such as food, liquids, and any other items that he might require.
5. Patient getting worse:
    a. Never continue ascent if the patient's condition is worsening.
    b. Treat the patient as a recurrence during treatment (see 6).
    c. Consider the use of helium-oxygen as a breathing medium for the patient (see 8).
6. Recurrence of symptoms:
    a. During treatment:
        1. Recompress to depth of relief (but never less than 30 feet or deeper than 165 feet except on decision of a medical officer).
        2. If a medical officer is available and the depth of relief is less than 60 feet, recompress to 60 feet and treat on table 6.
        3. If a medical officer is not available or the depth of relief is greater than 60 feet, complete the treatment according to table 4; i.e., remain at depth of relief for 30 minutes and complete remaining stops of table 4.
        4. If recurrence involves serious symptoms not previously present, take the patient to 60 feet and treat on table 6 or take the patient to 165 feet and treat on table 4.
    b. Following treatment:
        1. Recompress to 60 feet and use table 6 if a medical officer is available.
        2. If the depth of relief is less than 30-feet, recompress the patient to 30 feet and decompress from the 30-foot stop according to table 3.
        3. If the depth of relief is deeper than 30 feet, keep the patient at depth of relief for 30 minutes and decompress according to table 3.

TABLE 1–32.—*Notes on recompression*—Continued

6. Recurrence of symptoms—Continued
   b. Following treatment—Continued
      4. If the original treatment was on table 5 or 6, use table 6. If the original treatment was on table 5A or 6A, use table 6, 6A, or table 4. If the original treatment was on table 3, use table 6, 6A, or table 4.
      5. Examine the patient carefully to be sure no serious symptom is present. If the original treatment was on table 1 or 2, appearance of a serious symptom requires full treatment on table 6, 3, or 4.
   c. Using oxygen treatment tables during or following treatment:
      1. Table 6 can be lengthened by an additional 25 minutes at 60 feet (20 minutes on oxygen and 5 minutes on air) or an additional 75 minutes at 30 feet (15 minutes on air and 60 minutes on oxygen), or both. Table 6A can be lengthened in the same manner.
      2. If relief is not complete at 60 feet or if the patient's condition is worsening, the additional time above may be used or the patient can be recompressed to 165 feet and treated on table 2, 2A, 3, or 4 as appropriate.
7. Use of oxygen:
   a. Use oxygen wherever permitted by the treatment tables unless the patient is known to tolerate oxygen poorly.
   b. If a medical officer trained in diving is available, he may recommend the use of oxygen for patients who are known to tolerate oxygen poorly.
   c. Take all precautions against fire (see table 1–34).
   d. Tend carefully, being alert for such symptoms of oxygen poisoning as—
      1. Twitching of the face and lips.
      2. Nausea.
      3. Dizziness and vertigo.
      4. Vomiting.
      5. Convulsions.
      6. Anxiety.
      7. Confusion.
      8. Restlessness and irritability.
      9. Malaise or excessive tiredness.
      10. Changes in vision as blurring or narrowing of the visual field.
      11. Incoordination.
      12. Tremors of the arms and legs.
      13. Numbness or tingling of the fingers or toes.
      14. Fainting.
      15. Spasmodic breathing.
   e. Know what to do in the event of a convulsion:
      1. Halt ascent.
      2. Remove mask at once.
      3. Maintain depth.
      4. Protect the convulsing patient from injury but do not restrain or forcefully oppose the convulsive movements.
      5. Use a padded mouth bit to protect the tongue of a convulsing patient.
      6. If the patient is not convulsing, have him hyperventilate with chamber air for a few breaths.
   f. If oxygen breathing must be interrupted:
      1. On table 1, proceed on table 1A.
      2. On table 2, proceed on table 2A.
      3. On table 3, continue on table 3, using air.
      4. On table 5, 6, 5A, or 6A, allow 15 minutes after the reaction has entirely subsided and resume the schedule at the point of its interruption.
      5. On table 5, if the reaction occurred at 60 feet, upon arrival at the 30-foot stop, switch to the schedule of table 6.
   g. At the medical officer's discretion, oxygen breathing may be resumed at the 40-foot stop. If oxygen breathing is resumed, complete treatment as follows:
      1. Resuming from table 1A: breathe oxygen at 40 feet for 30 minutes and at 30 feet for 1 hour.
      2. Resuming from table 2A: breathe oxygen at 40 feet for 30 minutes and at 30 feet for 2 hours.
      3. In both cases, then surface in 5 minutes, still breathing oxygen.
      4. Resuming from table 3: breathe oxygen at 40 feet for 30 minutes and at 30 feet for the first hour, and then finish the treatment with air.

TABLE 1–32.—*Notes on recompression*—Continued

8. Use of helium-oxygen:
   a. Helium-oxygen mixtures in a ratio of about 80:20 can be used instead of air (not in place of oxygen) in all types of treatment and at any depth.
   b. The use of helium-oxygen mixtures is especially desirable in any patient who—
      1. Has serious symptoms which fail to clear within a short time at 165 feet.
      2. Has a recurrence of symptoms or otherwise becomes worse at any stage of treatment.
      3. Has any difficulty in breathing.
9. Tenders:
   a. A qualified tender must be in the chamber at all times.
   b. The tender must be alert for any change in the condition of the patient, especially during oxygen breathing.
   c. The tender must breathe oxygen if he has been with a patient throughout treatment using table 1 or 2.
      1. On table 1, breathe oxygen at 40 feet for 30 minutes.
      2. On table 2, breathe oxygen at 30 feet for 1 hour.
   d. A tender in the chamber only during the oxygen-breathing part of table 1 or 2 gains a safety factor by breathing oxygen for 30 minutes of the last stop, but it is not essential. Tenders may breathe oxygen during the use of table 3 or 4 at depths of 40 feet or less.
   e. When tables 5, 6, 5A, and 6A are used, the tender normally breathes air throughout. However, if the treatment is a repetitive dive for the tender or if tables 6 or 6A are lengthened, the tender must breathe oxygen during the last 30 minutes of ascent from 30 feet to the surface.
   f. Anyone entering the chamber and leaving before completion of the treatment must be decompressed according to standard diving tables.
   g. Personnel outside the chamber must specify and control the decompression of anyone leaving the chamber and must review all decisions concerning treatment or decompression made by personnel (including the medical officer) inside the chamber.
10. Ventilation of the chamber:
   a. All ventilation will be continuous and the volumes specified are measured at the chamber pressure.
   b. If ventilation must be interrupted for any reason, the time will not exceed 5 minutes in any 30-minute period. When the ventilation is resumed, twice the volume of ventilation will be used for twice the time of the interruption and then the basic ventilation will be used again.
   c. When air or a helium-oxygen mixture is breathed, provide 2 cubic feet per minute for a man at rest and 4 cubic feet per minute for a man who is not at rest, such as a tender actively taking care of a patient.
   d. When oxygen is breathed, provide 12.5 cubic feet per minute for a man at rest and 25 cubic feet per minute for a man who is not at rest. When these ventilation rates are used, no additional ventilation is required for personnel breathing air. These ventilation rates apply only to the number of people breathing oxygen.
   e. The above rules apply to all chambers that do not have facilities to monitor the oxygen concentration in the chamber. Chambers that can monitor oxygen concentration may use intermittent ventilation so that the oxygen concentration in the chamber does not exceed 22.5 percent. This ventilation also requires no additional ventilation for personnel breathing air.
   f. If an oxygen-elimination system is used for oxygen breathing (see app. B) the ventilation rate required for air breathing may be used and applies to all personnel, whether or not the oxygen-elimination system is used to obtain the correct ventilation rate.
11. First aid:
   a. First aid may be required in addition to recompression. Do not neglect it (see table 1–33 and app. A).
12. Recompression in the water:
   a. Recompression without a chamber is difficult and hazardous. Except in grave emergencies, seek the nearest chamber even if it is at a considerable distance.
   b. If water recompression must be used and the diver is conscious and able to care for himself:
      1. Use the deep-sea diving rig if available.
      2. Follow treatment tables as closely as possible.
      3. Maintain constant communication.
      4. Have a standby diver ready and preferably use a tender with the patient.
   c. If the diver is unconscious or incapacitated, send another diver down with him to control his valves and otherwise assist him.
   d. If lightweight diving outfit or scuba must be used, keep at least one diver with the patient at all times. Plan carefully for shifting rigs or cylinders. Have an ample number of tenders topside and at intermediate depths.

TABLE 1–32.—*Notes on recompression*—Continued

12. Recompression in the water—Continued
    - *e.* If depth is inadequate for full treatment according to the tables:
        - *1.* Take the patient to maximum available depth.
        - *2.* Keep him there for 30 minutes.
        - *3.* Bring him up according to table 2A. Do not use stops shorter than those of table 2A.
13. The most frequent errors related to treatment:
    - *a.* Failure of the diver to report symptoms early.
    - *b.* Failure to treat doubtful cases.
    - *c.* Failure to treat promptly.
    - *d.* Failure to treat adequately.
    - *e.* Failure to recognize serious symptoms.
    - *f.* Failure to keep the patient near the chamber after treatment.
14. ALWAYS KEEP THE DIVER CLOSE TO THE CHAMBER FOR AT LEAST 6 HOURS AFTER TREATMENT. (Keep him for 24 hours unless very prompt return can be assured.)

TABLE 1–33.—*Notes on artificial respiration*

1. Start artificial respiration immediately whenever a man is *not breathing* due to drowning or any other cause.
    - *a.* Never wait for mechanical resuscitator.
    - *b.* Delay *only* to stop serious bleeding (if possible have another person tend to such measures while you start artificial respiration).
    - *c.* Send *another person* for a medical officer or other competent aid.
2. Before starting, remove victim from the cause of his trouble; but do not waste time moving him any further than necessary.
3. *Get on with artificial respiration.* Leave details to others or try to get them done quickly between cycles.
    - *a.* Recheck position of victim:
        - *1.* In position for mouth-to-mouth resuscitation.
        - *2.* Head slightly lower than feet if possible, especially in drowning.
        - *3.* Chin pulled toward operator.
    - *b.* Recheck airway:
        - *1.* Remove froth, debris, or other material.
        - *2.* See that tongue stays forward; have someone hold it if it draws back (you can run a safety pin through tongue if necessary).
        - *3.* If *artificial respiration does not move any air, there is an obstruction.* Strangulation must be overcome (see app. A).
    - *c.* Loosen any tight clothing—collar, belt, etc.
    - *d.* Keep victim warm.
    - *e.* Check pulse. Combat shock.
4. Continue artificial respiration without interruption. (Minimum time is 4 hours unless victim revives or is pronounced dead by medical officer.)
    - *a.* Do not apply *too much* back pressure. (A strong operator can crack ribs of a small victim.)
    - *b.* If you become tired, let another operator take over. Do not break rhythm during shift.
    - *c.* Watch carefully for signs of return of natural breathing movements. If they appear, time your movements to assist them.
    - *d.* Shift to a mechanical resuscitator if one is available, ready, and operating properly.
    - *e.* If victim starts breathing for himself, watch him carefully. Resume artificial respiration if he stops or if movements become too feeble.
5. If victim revives, continue care:
    - *a.* Keep him lying down.
    - *b.* Remove wet clothes; keep him warm.
    - *c.* Give nothing by mouth until fully conscious.
    - *d.* Attend to any injuries.
    - *e.* Be sure he is seen promptly by medical officer.

NOTE

If victim has been underwater with any kind of breathing apparatus, he *may have air embolism.* This can seldom be ruled out in an unconscious diver, whether he is breathing or not, and recompression should be given if any doubt exists. Do not delay artificial respiration. Give it by some method on way to chamber and during recompression.

TABLE 1–34.—*Precautions in use of recompression chamber*

Preparedness

The personnel and facilities of every Navy diving activity must be ready to treat decompression sickness or air embolism at a moment's notice at any time.

1. The chamber and its auxiliary equipment must be in working order and ready for use. Follow routine of periodic tests and preventive maintenance. Check the following:
   a. The chamber itself—free of extraneous gear, equipped and ready.
   b. The air supply—banks charged, compressor ready to operate.
   c. Communication gear—functioning properly.
   d. Oxygen installation—cylinders full, demand valves operative.
   e. Medical kit—stocked and at hand.
2. Personnel must be trained in operation of equipment and be able to do any job required in treatment; definite assignment of responsibilities is required.
   a. Hold periodic training runs with rotation of personnel.
   b. Provide emergency bill, listing jobs and duties.

General Precautions in Use

1. Avoid damage to doors and dogs. Use minimum force required in "dogging down"; be sure dogs are released before pressure is reduced.
2. Provide ample chamber ventilation, especially when oxygen is being used.
3. Assure accurate timekeeping and recording.
4. Keep tender with patient especially when breathing oxygen.
5. Assure proper decompression of all persons entering chamber.

Prevention of Fire

1. Remove all combustible materials and replace with metal or fireproof construction (deck gratings, benches, etc.).
2. Use only fire-retarding paint; keep painting to minimum.
3. Keep chamber clean and free from all oily deposits and volatile materials of any kind. Keep all air filters clean.
4. Ventilate thoroughly after painting or unavoidable presence of any flammable substances.
5. Use no oil on any oxygen fitting or equipment.
6. Keep bedding and clothing to minimum. Be sure mattress, if used, is covered with fire-resistant material. Use flameproof bedding material. Be sure that clothing is free of grease and oil.
7. Locate all electrical switches outside chamber. Keep electrical system in perfect condition. Prohibit use of any electrical appliance in chamber during oxygen breathing.
8. Let no flame, matches, cigarette lighter, lighted cigarette, cigar, or pipe be carried into the chamber at any time.
9. Assure ample ventilation of chamber during use of oxygen and before any appliance is used.
10. Provide water and sand buckets.
11. Display the following warning prominently inside and outside the chamber:

WARNING

Danger of fire and explosion is much greater in an oxygen or a compressed-air atmosphere than in normal atmosphere at sea-level pressures. Do not admit flames, sparks, volatile or flammable substances, or unnecessary combustibles of any kind. Provide ample ventilation during oxygen breathing. Electrical appliances should not be used during oxygen-breathing periods or when the chamber atmosphere is compressed air.

1.6.3 AIR EMBOLISM AND RELATED ACCIDENTS

Causes

(1) As previously described, the same basic process (excessive pressure in the lungs sufficient to produce leakage of air) produces air embolism and related conditions. In diving, this process occurs because of the expansion of air retained in the lungs during ascent. For example, if a man holds his breath during ascent, the lung air will expand as the surrounding pressure decreases (Boyle's law). If it expands enough to fill the lungs completely, and the man still continues to hold his breath, the pressure in the lungs will become higher than that in the rest of the body. The lungs will overexpand, and at some point they will start to leak air—either into the blood vessels that go through the lungs or into the surrounding tissues, or both. Actual tears in the lung tissue usually occur in the process of overexpansion. If air enters the mediastinum in sufficient amounts and under enough pressure, it will make its way up toward the neck and appear under the skin as subcutaneous emphysema.

(2) Trapping of air in the lungs may result from several causes. The most common, in diving, is the voluntary holding of breath. Among amateur divers this breath holding is usually the result of a lack of understanding of the physics and physiology of diving. Breath holding may also come about as the result of panic. When panic occurs, it is instinctive to hold one's breath. Diseases of the lungs may produce pockets of air which do not empty on ascent or which cause restriction of the flow of air from areas of the lungs. The disease may be of recent origin, such as pneumonia, or it may be one which occurred earlier in life and caused such permanent changes as scarring.

(3) Pressure changes in extremely shallow depths may be sufficient to cause air embolism. Cases have occurred in depths as shallow as 12 feet. Air embolism and its related conditions most frequently occur in what is usually termed shallow-water diving. It has also become a problem of primary importance in the use of self-contained breathing apparatus.

Prevention

(4) Air embolism and its related conditions are best prevented by observing the following procedures or rules:

(*a*) *Careful selection of personnel.*—As in the prevention of decompression sickness, each candidate must be carefully evaluated. Those men who show evidence of lung disease or have a past history of asthma must be carefully evaluated by the medical officer.

(*b*) *Careful observation and evaluation of each man before he makes any dive.*—Any evidence of acute lung conditions must be reported by each diver to the medical officer. Colds, bronchitis, coughing, pain in the chest, or the like should be reported to and then carefully evaluated by the medical officer prior to a dive.

(*c*) *Proper, intensive training of every diver in the physics and physiology involved in diving.*—Every diver should be familiar with the sections of this manual concerning physics, physiology, and diving accidents. Many cases of air embolism have occurred, especially among civilians, simply because Boyle's law and its application to diving had never been explained.

(*d*) *Proper, intensive training of every diver in the use of any diving equipment he may be required to use.*—This requirement is especially important concerning the use of scuba. Training and proper indoctrination give the individual confidence which is important during times of danger to insure intelligent action will be taken and panic will not result.

(*e*) *Never hold your breath during ascent from a dive in which a breathing apparatus is being used.*—Breathe regularly during ascent. (A skindiver who is not using a breathing apparatus very rarely develops air embolism, simply because the volume of air in his lungs can never exceed that volume which he was able to hold while breathing at the surface.)

(*f*) *Exhale continuously while making an ascent from a dive in which air supply failed.*—When air supply fails or runs out, an emergency ascent becomes necessary. The ideal method for making an emergency ascent is accomplished by floating to the surface by means of natural buoyancy, or by means of assisted buoyancy from a lifejacket. During an ascent with no lifejacket, air is exhaled continually at such a rate that buoyancy is maintained, and the exhalation is sufficient to prevent overexpansion of the lungs. "Free ascent," as this procedure is termed, is difficult for the untrained individual and must never be taught at facilities which do not have the proper equipment and personnel to provide supervision of ascents and treatment of accidents that may result. *The presence of a recompression chamber in the immediate vicinity is absolutely necessary during any free-ascent training or buoyant-ascent* training. Ascent assisted by an external source of buoyancy (termed *buoyant ascent*) requires a slightly different technique than does free ascent. A fully inflated lifejacket will cause a much more rapid ascent through the water. The rate of ascent may be as much as 400 feet per minute. With this method, exhalation should start before ascent begins and must be rapid and continuous in order to prevent overexpansion of the lungs. (It is not within the scope of this manual to give the details of these ascent methods, and it is not feasible to attempt to teach such methods without actual training in the water under proper conditions.)

Diagnosis

(5) Air embolism is an extreme emergency. When it is present, the victim may die or suffer permanent brain damage unless he receives proper treatment (recompression) very promptly. *If a diver who has had any source of air (or other breathing medium) at depth is unconscious upon surfacing or loses consciousness shortly after surfacing, you must assume that he has air embolism and must act accordingly at once.* If the diver regains consciousness *before* recompression and shows no sign of brain injury, then air embolism is usually ruled out; but you must never wait to recompress the diver in the hope that this situation will happen. (The conditions related to air embolism, if they appear in the absence of air embolism, are seldom acute emergencies.)

Case History

(6) In order to develop air embolism or any of the related conditions, a diver must ascend from a depth greater than a few feet after using any source of air under pressure. This source need not be compressed air in the way we usually think of it. A case of air embolism occurred in a small boy who took an ordinary bucket down in the water to a depth of 11 feet. He breathed in the bucket until the air became foul. He then surfaced holding his breath. He was pronounced dead several hours later as the result of air embolism.

(7) The arteries of the brain are almost always involved immediately; and because the brain is extremely sensitive to reduced circulation of blood, there is rarely a delay of more than a minute or so before the development of signs and symptoms. Certainly, any symptoms (other than unconsciousness) developing more than 5 minutes after the ascent should *not* be considered air embolism. Other possible causes should be investigated.

Symptoms

(8) Symptoms developing from *air embolism* are dramatic and sudden in onset. They usually occur within seconds after the time of surfacing. In a case in which the leakage of air from lung tissue takes place at a relatively deep depth, the symptoms may start long before the diver reaches the surface. Many cases occur without the development of any symptoms prior to the onset of unconsciousness.

(9) Symptoms, if they do develop prior to the onset of unconsciousness, are primarily those of involvement of the brain. For example, the diver will experience weakness, dizziness, paralysis or weakness of extremities, visual disturbances such as blurring, all of which indicate involvement of the brain. Any symptoms that develop will then rapidly become more severe and be joined by others until unconsciousness occurs, usually within a matter of seconds.

(10) The diver may or may not experience discomfort or pain in the chest prior to or during the rupture of the lungs. Sometimes a victim will report that he felt a blow to the chest.

(11) When actual tearing of lung tissue takes place, the victim of an embolism will often have bloody froth at the mouth. When this froth is seen in a diver who loses consciousness on or before surfacing, it is a strong indication of air embolism. However, it is by no means always seen when this accident has occurred. Never assume that an unconscious diver *does not* have

air embolism simply because there is no bloody froth. (On the other hand, bloody froth can also appear after a lung squeeze; and blood from an ear or sinus squeeze or from a bitten tongue can sometimes be mistaken for bloody froth.)

(12) The *symptoms* of *mediastinal emphysema* are pain under the breastbone and, in extreme cases, shortness of breath or faintness due to interference with circulation as the result of direct pressure on the heart and large blood vessels.

(13) Unless it is extreme, *subcutaneous emphysema* has no symptoms, except perhaps a feeling of fullness in the neck and a change in the sound of the voice.

(14) The *symptoms* of *pneumothorax* are:

(*a*) Sharp pain in the chest, usually made worse by deep breathing.

(*b*) Shortness of breath.

Signs

(15) The *signs* that may be observed in a diver suffering from *air embolism* are, progressing from less serious to more serious:

(*a*) Bloody, frothy sputum.

(*b*) Staggering.

(*c*) Evidence of confusion or difficulty in seeing (for example, moving in the wrong direction or bumping into objects).

(*d*) Paralysis or weakness of extremities.

(*e*) Collapse.

(*f*) Unconsciousness.

(*g*) Convulsions.

(*h*) Cessation of breathing.

(Note that the onset may be so sudden that none but the most serious signs can be seen.)

(16) With *mediastinal emphysema*, the following *signs* may be seen:

(*a*) Blueness (cyanosis) of the skin, lips, or fingernails.

(*b*) Difficulty in breathing.

(*c*) Shock.

(17) With *subcutaneous emphysema*, the following *signs* may be seen:

(*a*) Swelling or inflation of the neck, sometimes to the extent that there is a resemblance to a bull frog.

(*b*) A crackling sensation (crepitation) when the skin is moved slightly.

(*c*) Change in sound of the voice.

(*d*) Difficulty in breathing or swallowing.

(18) With *pneumothorax*, the person may show any or all of the following *signs:*

(*a*) Blueness (cyanosis) of the skin, lips, or fingernails.

(*b*) Evidence of pain, such as grimacing or clutching that side of the chest which is involved.

(*c*) Tendency to bend the chest toward the side involved.

(*d*) Rapid shallow breathing.

Treatment

(19) The *treatment* of *air embolism* consists of *recompression* in a *recompression chamber*. This treatment reduces the size of the bubble and may permit resumption of normal circulation of blood in the brain. Recompress the patient without delay to a depth of 165 feet. Descend at the maximum rate that is within the capability of the tender or tenders to equalize. (The normal descent rate of 25 feet per minute does not apply to the treatment of air embolism.) If the tenders have difficulty equalizing, descent must continue regardless. After reaching 165 feet, follow Treatment Table 3, 4, 5A, or 6A, whichever is indicated by the response of the patient: If he *completely* recovers with 15 minutes, use table 5A. If he *completely* recovers within 30 minutes, use table 3 or table 6A. If he does not completely recover within 30 minutes, use table 4. (All these treatment tables are given in tables 1–30 and 1–31.) Be extremely watchful for any evidence of recurrence of symptoms during ascent.

NOTE

Having a case of air embolism when no recompression chamber is nearby presents very serious problems. The delay involved in getting the victim to a chamber may result in death or permanent injury. However, attempting to treat such a patient in the water presents so many difficulties and risks (especially if only scuba equipment is available) that this can seldom be recommended except where the nearest chamber is at great distance.

(20) Use oxygen where permitted by the treatment table, but discontinue it if there is evidence that oxygen breathing is producing lung irritation (pain or coughing) or difficulty in breathing. Note that a helium-oxygen mixture

can be used at any time during treatment with table 3 or 4. (See tables 1–30 and 1–32.)

(21) In a simple, uncomplicated case of *mediastinal* or *subcutaneous emphysema* where air embolism is not present, recompression is seldom desirable unless there is marked difficulty in breathing or evidence of impairment of circulation of blood because of pressure about the heart. If recompression is used, then table 3, table 4, table 5A, or table 6A must be used for decompression.

(22) In a case of *pneumothorax* uncomplicated by air embolism, do not use recompression. If it is severe and causes marked difficulty in breathing, the *treatment* required is direct removal of the air trapped between the lung and chest wall. This treatment should be done by a medical officer. It is accomplished by careful insertion of a long hypodermic needle into the air-filled space and withdrawal of the air by means of a syringe. The needle must be inserted no farther than necessary to reach the air. Care must be taken not to admit additional air during this procedure. This hazard can best be avoided by using a two-way petcock between the needle and the syringe so that a direct, free airway into the chest cavity never exists. Another emergency means to prevent such an airway consists of constructing a simple one-way flutter valve using a condom slit at one end with the normally open end tied securely about the end of the needle. This construction permits the air to escape; but no air can enter the chest cavity, and the lung will then expand.

(23) In any case of air embolism or related accidents, breathing may cease. In this case, artificial respiration must be started in addition to immediate recompression. Stimulants are indicated to help restore respiration. Shock must also be treated when it exists.

1.6.4 LOSS OF CONSCIOUSNESS

Causes

(1) *Loss of consciousness* during or after a dive is an acute emergency, and it may result from many different causes. Air embolism and serious forms of decompression sickness have been discussed and should always be considered when a diver loses consciousness. Simple fainting occurs occasionally. Any mishap that stops breathing or seriously interferes with any part of the respiratory process will also lead to unconsciousness. Especially when a diver loses consciousness under water, more than one accident may have occurred by the time he can be rescued. For example, loss of consciousness caused by oxygen poisoning or some other initial accident might then lead to drowning, air embolism, or even a head injury—or conceivably all three. It is often very difficult to determine exactly what has happened to the victim, and it is far more important to start treating him at once than to try to determine the cause. In reality, the supposed nature of the accident seldom will change the steps that should be followed in treatment.

Essentials of Treatment

(Table 1–29 presents the most important steps in treatment.)

(2) *Artificial respiration* must obviously be started without delay whenever a man is not breathing. *Recompression* should be given in almost every case of unconsciousness simply because it is seldom possible to be *certain* that it is not essential. Air embolism can result from only a few feet of ascent with breath holding or respiratory obstruction. Decompression sickness has been known to follow dives that were well within the no-decompression limits, and its symptoms may appear many hours after surfacing.

(3) Although the steps given in table 1–29 provide a sound basis for treating almost any case of unconsciousness, several problems can arise. Commonsense and good judgment must always be used.

(*a*) If transporting the victim to a chamber and recompressing him will make some other lifesaving procedure difficult or impossible, then it may be best to concentrate on the other measure instead, especially if it seems extremely remote that the victim has a condition requiring recompression. In general, it is safer to assume that recompression is essential and to make every effort to provide it and all other necessary measures. For example, it should almost always be possible to continue artificial respiration by some means while transporting the patient and recompressing him. Also, there are very few tests, treatments, or even surgical procedures that could not be performed in a chamber of usual size in a real emergency. Recompression can seldom do harm. Failure to recompress can lose a life needlessly.

(*b*) If the chamber is at a considerable distance, the likelihood that recompression will be beneficial is naturally reduced. But even in air embolism, recompression is worthwhile so long as the victim remains alive. Distance is never a sufficient excuse for not attempting to reach a chamber as rapidly as possible. Efforts to recompress an unconscious man in the water (see table 1–32) involve great difficulty and risk even when the conditions and available gear are ideal. It can seldom be recommended if any other source of action is possible.

(*c*) Where *unconsciousness* results from a less serious condition such as fainting, mild hypoxia, or carbon dioxide excess, consciousness will frequently return before the man can be recompressed. In such a case, recompression is unnecessary unless some abnormality, e.g., paralysis or some other neurological sign, remains and fails to show definite spontaneous improvement. With the milder conditions, recovery may occur very shortly after recompression is started, and in some cases the fact that recovery occurred under pressure may seem only a coincidence. However, it is *never* safe to assume that this was true. Any patient who regains consciousness during recompression deserves full proper treatment (no less than table 3, table 6, or table 5A).

(*d*) While following the steps in table 1–29, bear in mind that unconsciousness may have been caused by some medical emergency not directly related to diving. The more time that elapses after surfacing from a dive, the more likely this is to be the case. Do not fail to examine the patient for signs of injury or other abnormalities, and to insure that he is examined completely by a medical officer at the earliest opportunity. Recompression should not be delayed for this, and even positive findings of another condition will seldom rule out recompression; but it is important to be fully aware of all that is wrong with the patient so appropriate action can be taken.

1.6.5 RESPIRATORY ACCIDENTS

(1) Some of the most serious accidents in diving, especially in the use of scuba, are those that can *stop or seriously interfere with breathing* or with some other phase of the respiratory process (1.3.5). These accidents can all result in unconsciousness, even though in some cases breathing itself may continue for some time. In all such accidents, the proper initial treatment is the same as that specified for unconsciousness (see table 1–29 and 1.6.4). Special considerations are indicated in the discussions of the individual accidents. In most instances, these accidents are discussed more fully in section 1.3.

Drowning

(2) *Circumstances:*

(*a*) Drowning is extremely unlikely with a *deep-sea rig* but could occur in the event of—

1. Loss of helmet.

2. Being in head-down position with spit cock open or when leaning on chin button, or with torn or ruptured suit.

(*b*) Normally, as long as he remains upright and has air supply, a deep-sea diver can keep water out of his helmet even though his suit is badly torn.

(*c*) With lightweight gear, drowning can follow loss or ditching of the mask. (Interruption of air supply may necessitate ditching.)

(*d*) Numerous possibilities of drowning with self-contained breathing equipment include—

1. Loss or flooding of mask or mouthpiece.

2. Failure of gear or gas supply.

3. Surface exposure in rough water.

4. Overexertion, exhaustion.

5. Almost any mishap followed by failure of emergency procedures or panic.

6. Any accident causing unconsciousness.

(3) *Treatment:*

(*a*) See tables 1–29 and 1–33, and appendix A.

(4) *Prevention:*

(*a*) Adequate training and drill in emergency procedures.

(*b*) Proper equipment in good condition.

(*c*) Use of lifejacket with scuba; lifeline with lightweight outfit.

(*d*) Good diving practices; adequate preparations.

(*e*) Appropriate boats, floats, etc.; readiness for going to aid of diver in distress.

Hypoxia (Oxygen Deficiency)

(5) Usual *causes* of hypoxia in diving are—

(*a*) *Loss or inadequacy of air supply.* (This also causes carbon-dioxide excess, thus represents asphyxia. *Diver generally knows he is in trouble.*)

(*b*) Using up available oxygen in rebreathing-type apparatus (closed or semiclosed circuit). *There is seldom any warning.*

In *closed-circuit* apparatus:

1. Poor initial purge.

2. Use of gas other than pure oxygen.

In *semiclosed mixed-gas* apparatus:

1. Use of too-low oxygen concentration in mixture.

2. Too-low flow setting.

3. Accidental reduction or cessation of flow.

(6) *Symptoms:*

(*a*) Diver frequently notices nothing; loses consciousness without warning.

(*b*) Mental changes similar to those of alcohol intoxication may occur.

(7) *Signs:*

(*a*) Slowing up of responses, confusion, clumsiness, foolish behavior, and such.

(*b*) Unconsciousness.

(*c*) Cyanosis (blueness).

(*d*) Cessation of breathing in severe hypoxia; death if not treated promptly.

(8) *Treatment:*

(*a*) If under water with rebreathing apparatus, add oxygen to breathing bag immediately, if possible. Otherwise, get to surface and give fresh air.

(*b*) If still breathing and not suffering from another accident, fresh air will cause rapid recovery. Use oxygen if available.

(*c*) If unconscious, treat according to table 1–29.

(9) *Prevention:*

(*a*) Training, good equipment, etc.

(*b*) Special attention to proper purge in using closed-circuit apparatus.

(*c*) With mixed-gas apparatus, extreme care in maintenance and preparation; attention to any sign of flow reduction or other malfunction during dive.

Carbon Dioxide Excess

(10) Usual causes:

(*a*) Loss or inadequacy of air supply. Using too little air in deep-sea rig.

(*b*) Failure of carbon dioxide absorption in rebreathing scuba:

1. Canister too small or poorly designed.

2. Exhausted absorbent or poor filling.

3. Exceeding duration of canister.

4. Water leakage into canister.

(*c*) Overexertion or increased breathing resistance.

(*d*) Excessive "controlled breathing."

(11) *Symptoms:*

(*a*) *Sometimes none*, as in hypoxia (see (5) above).

(*b*) Usually notice labored breathing, air hunger.

(*c*) May have headache, dizziness, weakness, unusual perspiring, nausea.

(*d*) May note mental changes: inability to think clearly, confusion.

(12) *Signs:*

(*a*) Slowing up of responses, confusion, clumsiness, foolish actions, and such.

(*b*) Unconsciousness; may have muscular twitching in extreme case.

(*c*) Breathing usually continues.

(13) *Action:*

(*a*) Diver should stop, rest, ventilate; surface if practical.

(*b*) Bring diver up and provide fresh air. (Effects usually subside rapidly.)

(*c*) If unconscious, treat according to table 1–29.

(14) *Prevention:*

(*a*) Avoid causes.

(*b*) Rest when breathing becomes labored.

(*c*) Discontinue dive if breathing continues to be excessive or if mental changes are noted.

Asphyxia

(15) Asphyxia involves *both* hypoxia and carbon dioxide excess.

Usual causes:

(*a*) Loss or inadequacy of air supply.

(*b*) Obstructed breathing (strangulation).

(16) *Signs and symptoms:*

(*a*) Usually have labored breathing.

(*b*) May have headache, weakness, dizziness.

(*c*) Mental changes as in hypoxia and carbon dioxide excess.

(*d*) Cyanosis (blueness).

(*e*) Unconsciousness if asphyxia is severe, and convulsions.

(*f*) May have violent increase in breathing followed by cessation of breathing.

(17) *Action:*

(*a*) Diver should stop, rest, ventilate. Surface if practical.

(*b*) Bring diver up and give fresh air.

(*c*) If unconscious, follow steps of table 1–29.

(18) *Prevention:*

(*a*) Same as for hypoxia and carbon dioxide excess.

Strangulation

(19) Strangulation refers to *obstruction* of breathing. It will produce asphyxia if severe. Inhalation of foreign material such as chewing gum, a false tooth, or vomitus is the most likely *cause* of strangulation in diving. The diver may have spasm of the larynx caused by inhalation of water. Strangulation may be a complication of drowning and other conditions requiring artificial respiration.

(20) *Signs and symptoms:*

(*a*) Extremely difficult (usually noisy) breathing; choking.

(*b*) Unconsciousness if strangulation is severe or prolonged.

(*c*) Struggle to breathe eventually ceases.

(21) *Treatment:*

(*a*) Relieve cause if possible. If victim is conscious, encourage him to cough, pound him on back, hold inverted.

(*b*) If obstructing object is within reach, attempt removal with finger or forceps, but take care not to push it farther down the throat.

(*c*) Consider emergency tracheotomy if other measures fail.

(22) *Prevention:*

(*a*) Remove dentures; do not chew gum during a dive.

(*b*) Guard against strangulation in unconscious victims of any accident.

Carbon Monoxide Poisoning

(23) Carbon monoxide combines with hemoglobin in blood and prevents the blood from carrying oxygen. Basic difficulty, as a result, is that insufficient oxygen reaches the tissues (tissue hypoxia).

(24) *Usual cause* of carbon monoxide poisoning in diving is contamination of diver's air from the following:

(*a*) Compressor intake too close to exhaust.

(*b*) Flashing of lubricating oil in compressor.

(25) *Symptoms:*

(*a*) Frequently, no symptoms noted; unconsciousness without warning.

(*b*) Occasionally, tightness across forehead, headache, dizziness, nausea, weakness.

(*c*) Confusion and other mental changes similar to those of hypoxia.

(26) *Signs:*

(*a*) Failure to respond, clumsiness, bad judgment, and such may be noted by tender or buddy.

(*b*) Unconsciousness.

(*c*) Breathing ceases in severe cases.

(*d*) Abnormal redness of lips, nailbeds, or skin.

(27) *Treatment:*

(*a*) Get victim into fresh air. Give oxygen if available.

(*b*) If unconscious, treat according to table 1–29.

(*c*) Continue use of oxygen in chamber, using table 5 or table 6 as indicated by the patient's response.

(28) *Prevention:*

(*a*) Place exhaust downwind and as far from compressor intake as possible.

(*b*) Assure adequate maintenance and proper operation of compressors.

(*c*) Where any doubt exists, test air periodically for carbon monoxide.

Other Respiratory Accidents

(29) *Electrocution* can cause abrupt cessation of breathing.

(*a*) *Causes.* Rare in diving but can result from—

1. Accidents with underwater cutting and welding procedures.

2. Careless handling of lights, power tools, and other electrical equipment.

3. Use of electrical gear in bad condition.

(*b*) *Prevention:*

1. Comply with instructions in the Underwater Cutting and Welding Manual, NAVSHIPS 250–692–9.

2. Exercise special care and attention at all times when electrical appliances are in use around the diving station.

3. Repair or replace defective equipment promptly.

(*c*) *Action.* Free victim from source of current promptly, but exercise extreme caution to avoid electrocution of rescuer. Cut power first if at all possible.

(*d*) *Treatment:*

1. Give artificial respiration (see table 1–33 and app. A).

2. Get medical assistance at once.

NOTE

Electrocution frequently stops heart action as well as breathing (see app. A).

3. Continue artificial respiration until victim revives or is pronounced dead.

4. When a victim of electrocution revives, keep him strictly at rest for 24 hours even though consciousness and heart action (pulse) have returned to normal.

(30) *Poisonous gases* other than carbon monoxide are unlikely to be met with in diving itself, but a variety of them may be encountered in salvage operations.

(*a*) *Prevention* requires exercise of great caution and use of approved procedures in opening, ventilating, and entering holds and closed spaces of all kinds.

(*b*) *Action.* Be extremely careful that attempts to rescue victim do not result in similar accident to rescuers.

(*c*) *Treatment:*

1. Artificial respiration.

2. Medical assistance.

3. Other measures as required by nature of poisoning.

1.6.6 OXYGEN POISONING (see 1.3.11)

Oxygen poisoning in diving *can result* from any exposure to increased oxygen partial pressures beyond acceptable limits. This poisoning can be caused by the following:

(*a*) Use of closed-circuit oxygen (or any other type of apparatus supplied with oxygen) for working dives beyond specified depth-time limits (oxygen limits).

(*b*) Use of excessively high oxygen concentrations in breathing media for helium-oxygen or nitrogen-oxygen diving, or exceeding of proper depths and times for mixtures and flows used.

(*c*) Failure to remain at rest during oxygen phase of helium-oxygen decompression or therapeutic use of oxygen in chamber.

(*d*) Accumulation of carbon dioxide in self-contained apparatus with increased oxygen partial pressure.

(*e*) Unusual susceptibility to oxygen poisoning.

Symptoms

(2) The main consequence of oxygen poisoning is *convulsion.* Less serious symptoms sometimes precede convulsion. If one of these symptoms appears and is recognized in time, the diver may be able to lower the partial pressure of oxygen (by coming up) and avert convulsion. The most common warning symptoms are:

(*a*) Muscular twitching usually appearing first in the face.

(*b*) Nausea.

(*c*) Dizziness.

(*d*) Abnormalities of vision or hearing.

(*e*) Difficulty in breathing.

(*f*) Anxiety and confusion.

(*g*) Unusual fatigue.

(*h*) Poor coordination (clumsiness, etc.).

Signs

(3) Prior to convulsion, the only *sign* likely to be observed is twitching. Once convulsion occurs, the sequence of events and signs is usually about the same.

(*a*) Consciousness is lost at the onset of convulsion. Breathing stops during "stiff" phase.

(*b*) Violent convulsive movements may continue for a minute or two.

(*c*) Biting the tongue, various physical injuries caused by striking hard objects, and drowning may occur during convulsion. Air embolism is possible with ascent during convulsion.

(*d*) Breathing generally resumes spontaneously after convulsion.

(*e*) Victim remains unconscious for several minutes after relaxing from convulsion.

(*f*) A period of semiconsciousness follows, with irrational behavior, great restlessness, and intermittent sleep. This phase usually lasts from 30 minutes to 1 hour.

Treatment

(4) Convulsions almost invariably stop before any active treatment can or need be applied. Concentrate on preventing drowning and injury. Action depends largely on circumstances.

(*a*) In self-contained diving—

1. Buddy should bring diver up promptly, preferably feet first, despite danger of air embolism from ascent during convulsion. (Drowning is a greater hazard.)

2. At surface, inflate victim's lifejacket and keep his face out of water.

(*b*) In helium-oxygen decompression, follow procedure given in 1.5.4(21).

(*c*) In recompression chamber (surface decompression using oxygen, oxygen tolerance tests, treatment) the following steps should be taken:

1. Remove mask.

2. Hold chamber at same depth until breathing resumes.

3. Use padded mouth bit to prevent tongue biting.

4. Prevent injury by falling or hitting objects, but do not try to oppose convulsive movements.

5. Turn on stomach with face to side to prevent inhalation of secretions or "swallowing tongue."

(*d*) In all cases—

1. Start artificial respiration if normal breathing fails to resume. Check for airway obstruction.

2. Watch victim carefully. Obtain medical assistance.

3. Recompress if diver was brought up during convulsion or if there is any other reason to suspect air embolism.

Prevention

(5) The seriousness of oxygen poisoning in diving makes prevention extremely important. Therefore, apply the following rules:

(*a*) Be sure that all divers have had the oxygen tolerance test.

(*b*) Carefully observe specified depth-time limits for use of oxygen apparatus for working dives (oxygen limits).

(*c*) Follow instructions carefully in use of semi-closed-circuit scuba.

(*d*) Avoid exertion when using oxygen for decompression or in treatment. Avoid overexertion when using self-contained equipment.

(*e*) Assure efficient absorption in rebreathing apparatus to prevent carbon dioxide buildup.

(*f*) Be alert for warning symptoms when oxygen poisoning is possible. Come to shallower depth (if possible, surface and breathe air) if such a symptom develops. Never *depend* on the appearance of warning symptoms. *Observe the limits!*

(*g*) *Never charge demand apparatus with oxygen.*

1.6.7 NITROGEN NARCOSIS (see 1.3.10)

Cause

(1) The nitrogen in the air begins to have intoxicating effects at about 100 feet. At depths much over 200 feet, most divers are too narcotized to work effectively or safely.

Symptoms and Signs

(2) The effects of nitrogen narcosis are similar to those of alcohol intoxication. Individuals differ not only in susceptibility but also in the nature of their reactions. Effects usually include the following:

(*a*) Loss of judgment and skill.

(*b*) False sense of well-being.

(*c*) Lack of concern for job and own safety.

(*d*) Difficulty accomplishing even simple jobs.

(*e*) Foolish behavior and inappropriate actions.

(*f*) Near unconsciousness in highly susceptible men at great depth.

Treatment

(3) No treatment is required. The effects disappear rapidly with ascent to shallower depths. There are no aftereffects.

Prevention

(4) Nitrogen narcosis can be *prevented* only by avoiding exceptionally deep dives using air.

Where such dives must be made, observe the following:

(*a*) Use only mature, stable, experienced divers.

(*b*) Make sure that the diver understands the effects of narcosis and knows how to act accordingly.

(*c*) Diver should not exceed required descent rate.

(*d*) Diver should ventilate thoroughly when he reaches bottom.

1.6.8 SQUEEZE

(1) As previously discussed, the term *squeeze* (or barotrauma) refers to any injury that occurs as a result of the diver's inability to equalize pressure between a closed air space and the outside water pressure. If an air space within the body (or attached to it) has rigid or semirigid walls, it must be equalized by free entry of air. (Nonrigid air spaces equalize simply by compression.)

Middle-Ear Squeeze

(2) *Cause:*

(*a*) Diving with blocked eustachian tube.

(*b*) Failure to "pop" ears on descent.

(3) *Symptoms:*

(*a*) Pain in ear during descent.

(*b*) Sudden relief of pain if eardrum ruptures.

(4) *Signs* (dependent on extent of damage):

(*a*) Redness and swelling of eardrum.

(*b*) Bleeding into eardrum or middle-ear space.

(*c*) Rupture of eardrum with bleeding.

(*d*) Spitting up of blood.

(*e*) Bleeding to outside if eardrum is ruptured.

(5) *Treatment:*

(*a*) Report to medical officer or corpsman.

(*b*) Mild case without rupture. Avoid pressure until:

1. Damage heals.

2. Ears can be readily cleared.

(*c*) Ruptured eardrum:

1. No diving until healed (usually about 2 weeks).

2. Keep water and all objects and materials (including medications) out of ear. (*Keep hands away from ears!*)

3. Return to medical officer at once if pain increases or if drainage appears. (These signs may indicate infection requiring antibiotic treatment.)

(6) *Prevention:*

(*a*) Do not accept men who cannot pass pressure test.

(*b*) "Pop" ears properly during descent:

1. Swallow or yawn.

2. Move jaw.

3. Blow gently against closed nostrils.

(*c*) Do not dive while having head cold or infection that blocks eustachian tubes.

(*d*) Use nose drops, spray, or inhaler for mild difficulty.

NOTE

If eardrum ruptures when diver is bareheaded in cold water, severe dizziness (sometimes with nausea and vomiting) can result. The diver may be so completely confused that he may be unable to find his way to the surface. (This is another example of the value of the buddy system and the lifejacket in self-contained diving.) Dizziness passes when water in the ear warms to body temperature.

External-Ear Squeeze

(7) *Cause:*

(*a*) Suit squeeze (see (31) below).

(*b*) Hood sealing over external ear.

(*c*) Use of ear plugs.

(8) *Symptoms:*

(*a*) Pain on descent even though able to "pop" ears.

(*b*) Feels almost same as middle-ear squeeze; pain stops if eardrum ruptures.

(9) *Signs:*

(*a*) Drum may have same appearance as in middle-ear squeeze.

(*b*) Often see blood blisters on or around eardrum or in canal.

(*c*) Eardrum may be ruptured, but bleeding to outside *does not* necessarily mean rupture.

(10) *Treatment:*

(*a*) Same as in middle-ear squeeze (see (5) above). (*Keep hands away from ears!*)

(*b*) Report any sign of infection.

(11) *Prevention:*

(*a*) If using closed rubber swimsuit, be sure to admit air for equalization during descent. (Pinch face seal at junction with mask to make a channel.)

(*b*) Line hood (ear area) with flannel or porous rubber to prevent sealing.

(*c*) Never use ear plugs!

Sinus Squeeze

(12) *Cause:*

(*a*) Blockage of opening leading from nose to sinuses.

(*b*) Most likely to occur during colds and other infections.

(13) *Symptoms:*

(*a*) Increasing pain in face (above, below, between, or behind the eyes) during descent.

(*b*) Pain relieved by ascent.

(14) *Signs:*

(*a*) Blood and mucous discharge from nose upon surfacing.

(*b*) Tenderness over sinus areas.

(15) *Treatment:*

(*a*) Avoid diving until cause subsides.

(*b*) Use nose drops, spray, or inhaler to promote drainage.

(*c*) Report to the medical officer; return promptly in case of pain, pus drainage, or other signs of possible infection.

(*d*) Use antibiotics for treatment of infection only under the medical officer's direction.

(16) *Prevention:*

(*a*) Avoid diving if you have a head cold.

(*b*) Use nose drops, spray, or inhaler for mild difficulty.

(*c*) Discontinue dive promptly if sinus pain develops.

Lung (Thoracic) Squeeze

(17) *Cause:* Squeeze occurs when gas in the lungs is compressed to less than residual volume (fig. 1–24).

(*a*) Too deep a descent during skindive.

(*b*) Breath held during descent with diving equipment.

(*c*) Failure of self-contained gear or gas supply during descent.

(*d*) Also occurs in generalized squeeze with deep-sea rig (see (20) below), and occasionally with mask squeeze.

(18) *Symptoms and signs:*

(*a*) Sensation of chest compression during descent.

(*b*) Pain in chest (occasional symptom).

(*c*) Difficulty in breathing on return to surface.

(*d*) Bloody, frothy sputum.

(19) *Treatment:*

(*a*) Bring diver to surface.

(*b*) Place in "drainage" position; try to clear blood from mouth.

(*c*) Give artificial respiration if not breathing.

(*d*) Use oxygen if breathing is labored or hypoxia appears to be present.

(*e*) Secure help of medical officer promptly. (Most cases should be hospitalized at least for observation.)

(*f*) Prevent and treat for shock.

(*g*) Give antibiotics to prevent infection.

Body Squeeze (With Deep-Sea Rig)

(20) The helmet is a closed, rigid air space applied to the body. Normally, proper control of air supply and exhaust prevent the helmet from producing squeeze; but certain conditions can cause the helmet to squeeze the diver's head and shoulders (and thus, in effect, his whole body). This is one of the most serious of all diving accidents.

(21) *Causes:*

(*a*) Falling while submerged. (Note that a fall in shallow water is more serious than a fall of the same distance in deep water) (1.2.4(21)).

(*b*) Failure to open air-control valve enough to keep pace with rate of descent.

(*c*) Loss of pressure in airhose (because of rupture of hose or failure of supply) with absence or failure of nonreturn valve.

(*d*) Loss of air from suit when inflow is small and exhaust valve is open too far.

(22) *Symptoms:*

(*a*) If symptoms are mild, diver may note only tightness of suit about chest and difficulty in inhaling.

(*b*) Condition can proceed to body being forced into helmet.

(23) *Signs:*

(*a*) If symptoms are mild, observer may note nothing.

(*b*) If they are more severe, signs may include:

1. Bleeding from nose, lungs, or eyes.

2. Swelling of tissues of head, neck, and shoulders; bleeding into the skin and membranes.

3. Unconsciousness.

4. Actual molding of diver into helmet.

(24) *Treatment:*

(*a*) Onset of squeeze is corrected by increasing air pressure in suit.

(*b*) Measures required depend on severity.

1. Treatment is same as for lung squeeze (1.6.8(19)).

2. Use cold packs on areas of skin bleeding.

3. Secure medical help at once; hospitalize victim unless squeeze is mild or unless recompression is required.

(*c*) As in every case where a diver must be pulled up before normal end of dive, consider need for decompression and provide it in chamber if necessary.

(25) *Prevention:*

(*a*) Always check nonreturn valve properly before every dive.

(*b*) Use volume tank on compressor; avoid using overaged hose.

(*c*) Always descend under control:

1. Diver must be able to stop his own descent by hanging on to descending line.

2. Tender must never let lifeline and airhose run through his hands.

(*d*) Always open air-control valve sufficiently during descent.

(*e*) Take great care to avoid falling from the ship or stage, from what you are working on underwater, or falling off ledges, etc., onto the bottom.

(*f*) If falling, open air-control valve as rapidly as possible and tell tender to pull in slack and hold on, but take care to avoid blowup following the fall. (Blowup is generally a less serious accident than a bad squeeze.)

Face-Mask Squeeze

(26) *Cause:*

(*a*) With self-contained apparatus and eye-nose mask: Too rapid descent with failure to equalize by letting air out through nose. (Never wear goggles!)

(*b*) With full-faced mask of lightweight rig: Same causes as with body squeeze (see (20) above).

(*c*) With full-faced mask as part of scuba rig: Failure of gas supply or demand valve, or failure to add gas to rebreathing unit upon descent.

(*d*) Causes of lung squeeze (see (17) above) can sometimes also produce face mask squeeze.

(27) *Symptoms:*

(*a*) Sensation of suction applied to face.

(*b*) Pain and squeezing sensation.

(*c*) Inability to breathe.

(28) *Signs* may include:

(*a*) Face swollen and bruised; whites of eyes are bright red.

(*b*) Bleeding from nose, lungs, eyes.

(*c*) Protrusion of eyes with hemorrhage in eyeball, behind it, and in membranes lining lids.

(*d*) Signs of lung squeeze if this has also occurred.

(*e*) Signs of suffocation in severe cases.

(29) *Treatment:*

(*a*) Administer artificial respiration if diver is not breathing.

(*b*) Provide treatment the same as for lung squeeze if required (see (19) above).

(*c*) Apply cold packs to bruised or bleeding areas.

(*d*) Give sedatives and pain-relieving drugs if required.

(30) *Prevention:*

(*a*) Descend under control in any dive, even with self-contained equipment or in skindiving. Do not use excessive weight to descend rapidly.

(*b*) Always use nonreturn valve with lightweight rig; test it before each dive. Be sure that your air supply is reliable and that your hose is good.

(*c*) Be positive that cylinders are turned on and that equipment (or bypass) is functioning properly.

(*d*) If pressure in the lightweight mask starts to drop (squeeze sensation begins), flood mask promptly; then ditch weighted belt and make free ascent exhaling all the way. Never ditch mask and lifeline except as a last resort when line is fouled and air supply is lost.

Suit Squeeze

(31) *Cause:*

Closed, dry-type swimsuits generally have air spaces in the folds, and these will not compress completely on descent. External-ear canals also form closed, rigid space within hood. Unless air is admitted to suit to equalize these spaces, descent beyond a certain depth will produce suit squeeze which generally includes external-ear squeeze (see (7) above).

(32) *Symptoms:*

(*a*) Pinching sensation of skin in area of folds in suit material or of fittings inside a suit.

(*b*) Symptoms of external-ear squeeze (see (8) above).

(33) *Signs:*

(*a*) Raised welts with skin bleeding in areas of squeeze.

(*b*) Signs of external-ear squeeze (see (9) above).

(34) *Treatment:*

(*a*) Skin usually requires no treatment. Cold applications are useful when there is bleeding.

(*b*) See treatment of external-ear squeeze (see (10) above).

(35) *Prevention:*

(*a*) Provide a means of admitting air to equalize suit pressure.

(*b*) Stop descent when pinching or ear pain develops.

(*c*) Equalize by getting air from face mask to go past face seal into hood.

1.6.9 GAS EXPANSION (see 1.3.8)

(1) Most of the air-containing structures of the body vent expanding gas readily upon ascent. Even a middle ear or sinus that equalizes with difficulty upon descent rarely gives trouble upon ascent. However, there are a few exceptions to this rule, and they should be kept in mind.

Air Embolism

(2) Air embolism and related accidents have been fully discussed. These accidents can result from gas expansion in the lungs during ascent, but they rarely happen except when the diver makes the mistake of holding his breath.

Ears and Sinuses

(3) On very rare occasions, air becomes trapped in a middle ear or sinus during ascent. Such an event will cause considerable pain, and it is conceivably possible for rupture of an eardrum to occur. A sinus that has been squeezed going down will frequently contain free blood or fluid, and this will sometimes be expelled by the *expansion* of *gas* upon ascent. Slowing the rate of ascent is usually all that is necessary to allow trapped gas to escape without causing harm.

Intestinal Tract

(4) *Cause:* Gas pockets in the gastrointestinal tract do not cause the diver difficulty upon descent because the nonrigid walls of the tract allow free compression. If no gas is added during the dive, ascent will cause only reexpansion to the original volume. However, if a diver swallows air while under pressure, or if his intestines form an exceptional amount of gas during the dive, the added amount of gas will have to be expelled during ascent. Familiar maneuvers generally accomplish this without difficulty. However, gas that happens to be too far from either end of the tract to readily escape can occasionally cause trouble.

(5) *Symptoms:*

(*a*) Mild: Sensation of abdominal fullness.

(*b*) Moderate: Abdominal pain and cramping.

(*c*) Severe: Severe pain; fainting.

NOTE

Fainting is caused by reflexes and is not necessarily a result of pain.

(6) *Treatment:*

(*a*) Stop ascent before pain becomes severe.

(*b*) Redescend sufficiently to relieve pain.

(*c*) Attempt to belch and break wind; *but note that overzealous attempts to belch may result in swallowing more air.*

(*d*) Resume ascent cautiously.

(*e*) Be sure topside (or buddy) realizes difficulty.

(7) *Prevention:*

(*a*) Reject men with history of many stomach and bowel disorders.

(*b*) Do not dive if stomach or bowel is upset.

(*c*) Watch diet before diving. (Avoid foods you have found likely to produce intestinal gas.)

(*d*) Avoid swallowing air during dive. Avoid chewing gum during dive (causes air swallowing, and men have strangled on inhaled gum).

1.6.10 BLOWUP

(1) Blowup is one of the most serious accidents associated with diving in suit and helmet. It is extremely rare in self-contained diving but can occur in several ways.

Cause

(2) In deep-sea or helium-oxygen rig:

(*a*) Any mishap or error that causes overinflation of dress; poor adjustment of air-control and exhaust valves, or plugging of exhaust openings.

(*b*) Loss of shoe or weights.

(*c*) Allowing legs to be higher than body (if legs are not properly laced or shoes are too light).

(*d*) Too strong or rapid a pull by tenders. Suddenly breaking free from being stuck in mud.

(*e*) Strong tide causing diver to lose hold on bottom or descending line, thus sweeping him to surface.

(3) In self-contained diving:

(*a*) Unintentional dropping of weights.

(*b*) Accidental overinflation of breathing bag.

(*c*) Excess air in closed dry suit as result of efforts to equalize suit squeeze; failure of vent valves on suit during ascent.

(*d*) Unintentional inflation of lifejackets.

Consequences

(4) Accidental blowing up may be injurious in ways such as:

(*a*) Air embolism, if breath is held during blowup even from extremely shallow depth (i.e., 7 feet above diver's head).

(*b*) Decompression sickness, if diver required decompression stops or was close to nondecompression limits. (The rapid ascent of blowup may cause trouble even in a dive not requiring stops.)

(*c*) Mechanical injury resulting from striking bottom of boat or other object at surface.

(*d*) Squeeze may result from falling back into deeper water after reaching surface and exhausting air from diving dress.

(*e*) Drowning not unlikely to occur if suit ruptures at surface.

Prevention

(5) In addition to guarding against the causes listed in (2) and (3) above, give attention to these points:

(*a*) Prohibit use of controlled blowup as a means of ascent.

(*b*) *Exhale* continuously if blowup occurs.

(*c*) Tenders: Take in at once all slack in diver's lines when diver reaches surface after blowing up.

(*d*) Diver: Exhaust only enough air to prevent rupture of suit and retain positive buoyancy until tenders have taken in slack.

Treatment

(6) Think of all the mishaps that may have occurred in the course of the blowup and act accordingly.

(*a*) If diver is unconscious, recompress immediately (probable air embolism).

(*b*) If dive did not require decompression and diver appears all right, watch him closely and keep him near recompression chamber. If symptoms of decompression sickness develop, treat according to treatment tables (tables 1–30 and 1–31).

(*c*) If dive did require decompression, follow procedure specified in 1.5.6.

(*d*) Apply first aid and other measures as required for injuries if there are any.

1.6.11 FOULING

(1) Accidents that prevent a diver's ascent are more common in surface-supplied diving than with scuba, but while the diver with lifeline and airhose may be more likely to become fouled, he at least has an ample air supply to use while the difficulty is being corrected. The scuba diver may be able to escape by ditching his equipment, but he will then face additional risks in making a free ascent.

Causes

(2) Possible causes of fouling include the following:

(*a*) Entanglement of lifeline, airhose, cylinders, other equipment, or the body itself with some underwater obstruction. (Stray lines and kelp are a particular hazard to the scuba diver.)

(*b*) Cave-in of tunnel or shifting of heavy objects near diver or in route of exit from wreck.

Consequences

(3) Assuming that he is eventually released, the surface-supplied diver generally suffers from no more than the following:

(*a*) Fatigue, exhaustion, exposure, and their possible consequences.

(*b*) Need for prolonged decompression. Decompression sickness occurs if this is not provided.

(*c*) Possible physical injury from cause of entrapment.

(4) The scuba diver is susceptible to the same consequences. In addition, he must be concerned about the following:

(*a*) Using up gas supply with consequent asphyxia.

(*b*) Air embolism in improperly executed free ascent.

Action

(5) Whether a diver emerges safely from fouling depends very much on his own actions even though the help of another diver is often required to free him. The diver must observe the following:

(*a*) Remain calm; think.

(*b*) Describe situation to tender or call buddy's attention to situation.

(*c*) Carefully and systematically attempt to determine cause of fouling and clear self. Use knife cautiously to avoid cutting airhose or breathing apparatus.

(*d*) In fouling with self-contained apparatus, regard ditching and free ascent as a last resort; but prepare to do this in case it proves necessary.

(*e*) If efforts to clear prove futile, be quiet and wait for aid.

(*f*) Remember that frantic, ill-planned efforts not only usually fail but can make the situation worse. Futile struggling and panic can result in death from exhaustion and shock.

Prevention

(6) Being aware of possible causes of fouling and using proper precautions can usually avert fouling.

(*a*) Always inspect area as well as possible to detect obstructions on which lines or other equipment might foul.

(*b*) Note and remember on which side of an obstruction you pass and return the same way. Go over, rather than under or around, an obstruction when possible.

(*c*) Have another diver tend lines outside when entering a space in which fouling could occur. If using self-contained apparatus, use a snap-on buddy line if you must proceed into a space alone and outside of your buddy's visual range.

(7) Ability to go to the aid of a fouled diver is the main reason for having a standby diver ready in surface-supplied diving, and one of the many reasons for insisting on the buddy system in self-contained diving.

Treatment

(8) When a fouled diver is freed, give careful attention to the decompression he requires and be ready to treat him for exposure or any injuries.

1.6.12 PHYSICAL INJURY

Mechanical Injury

(1) Divers sometimes sustain a variety of mechanical injuries from external violence during both underwater and surface phases of diving operations.

(*a*) When injury occurs under water, bring the diver to the surface as soon as it is safe to move him.

(*b*) Apply first aid as required.

(*c*) Obtain medical assistance unless injury is trivial.

(2) *Comprehensive first aid* is beyond the scope of this manual. All divers and diving personnel should be familiar with at least its basic principles (app. A).

Sonar Damage

(3) The only known biological effect of high-intensity sonar is damage to the ear which causes temporary or permanent hearing loss. Although there has been much speculation concerning possible injury to divers resulting from the operation of powerful sonar in their vicinity, to date there has been no documented case of such injury. This lack of documented injury could, perhaps, be due to the fact that divers have generally avoided such exposures.

From several studies it has been concluded that a free-swimming diver, protected with a wet-suit hood, can approach within 100 yards of any known sonar system. The protection of the hood depends upon its fit and upon how much of the face and skull it covers. Without a hood, a diver could approach within 600 yards of an operating sonar, but for safety he should probably always stay at least 3,000 yards away.

All sonar operation should be suspended while divers are working in the immediate vicinity. If sonar transmission is a hazard, the diver should be protected with a hood. He should remember that if the noise does not hurt his ears there is no immediate danger. If the sound is uncomfortably loud, he should remove himself from the area. If possible, he should surface, determine where the transmissions are coming from, and move away.

Burns

(3) *Chemical burns* (which might result from contact with the Baralyme used in helium-oxygen diving) deserve special comment. Baralyme is moderately caustic (alkaline, like lye) and can cause burns. In the event of such burns, follow these instructions:

(*a*) Flush immediately the affected area with large quantities of water. Make sure that any adhering particles of material are washed off or otherwise removed at once (see app. A).

(*b*) Use only *weak acids* like vinegar in attempts to neutralize the material. (Vinegar is preferable to boric acid solution because it is not poisonous if taken by mouth. The best neutralizing agent to have at hand is diluted vinegar—one part vinegar to one part water; or the equivalent strength of acetic acid diluted to a 2-percent solution.)

(*c*) *Use only large quantities of water for burns involving the eye.*

(*d*) Follow thorough washing of the eye with application of dressing of sterile-dry gauze or Vaseline-impregnated gauze. (Boric acid ointment should be used only on small areas.) Use sterile mineral oil in the eye.

(*e*) Notify medical officer at once.

NOTE

Acid burns are rare in diving. If they occur, follow the same treatment, relying mainly on flushing burned area with large quantities of water and avoiding use of strong neutralizing agents. (For acid burns, only *weak bases* like baking soda should ever be used.)

1.6.13 BLEEDING

Causes

(1) Bleeding from mouth, nose, or ear is a sign of some minor or major accident rather than a condition in its own right. Conditions causing it are discussed elsewhere. The following are conditions to consider in the situations indicated, but they are not invariable diagnoses.

(2) Bleeding from mouth:

(*a*) Unconscious diver, blood not frothy:

1. Convulsion with bitten tongue (inspect tongue for injury). Oxygen poisoning is most common cause, but convulsion can also occur in other conditions.

(*b*) Unconscious diver, frothy blood:

1. Lung rupture and air embolism.

2. Severe thoracic squeeze (most likely to occur in deep-sea skindiving).

(*c*) Frothy blood, diver otherwise in good condition except for possible difficulty in breathing:

1. Mild lung squeeze in deep-sea skindiving.

(*d*) Diver in good condition, nonfrothy blood:

1. Usually drainage from eustachian tube following middle-ear squeeze.

2. Condition related to bleeding from nose.

(3) Bleeding from the nose is usually associated with bleeding from the mouth (see preceding paragraph) or comes from—

(*a*) Drainage from eustachian tube after middle-ear squeeze.

(*b*) Drainage from sinus following sinus squeeze.

(*c*) *Nosebleed* from too vigorous blowing in an attempt to "pop" ears on descent, or unrelated cause.

(4) External bleeding from ear usually signifies the following:

(*a*) Rupture of eardrum caused by inability to equalize during descent.

(*b*) Ear-canal damage caused by external-ear squeeze if diver was wearing hooded suit. (Rupture may also be, but is not necessarily, present in these cases.)

Treatment

(5) Treatment depends on the cause and on the condition of diver. Frequently no treatment is needed. Inform the medical officer promptly if a serious condition is suspected or if bleeding is profuse or shows no sign of stopping.

NOTE

Bleeding from any open wound should be promptly stopped (see app. A).

1.6.14 OVEREXERTION AND EXHAUSTION

Causes

(1) Every man's ability to do hard work has definite limits even under the best conditions. Many different situations can lead a man to try to exceed these limits. These situations include:

(*a*) Working against strong currents or on unusually muddy bottom.

(*b*) Diving job requiring heavy exertion or unusually prolonged task.

(*c*) Wasting effort early in dive.

(*d*) Efforts of the diver to free himself when fouled, particularly if efforts are badly planned and ineffectual.

(2) Several conditions can reduce a man's ability to do hard work; for example:

(*a*) Excessive breathing resistance in self-contained breathing apparatus.

(*b*) Carbon dioxide buildup caused by the following:

1. Inadequate helmet ventilation.

2. Failure of absorption system in scuba.

3. Excessive dead space.

4. Use of controlled breathing.

(*c*) Bad air, breathing mixture too low in oxygen, or carbon monoxide poisoning.

(*d*) Excessive cold or inadequate protection.

Symptoms

(3) Symptoms of overexertion and exhaustion include the following:

(*a*) Extreme fatigue.

(*b*) Increasing weakness.

(*c*) Labored breathing.

(*d*) Anxiety and tendency toward panic.

Treatment

(4) Diver should do the following:

(*a*) Stop and rest if possible.

(*b*) Inform buddy or tender.

(*c*) Terminate dive if resting fails to help.

(*d*) Surface when practical, observing proper rate of ascent and decompression stops if required.

(5) Buddy should do the following:

(*a*) Render all possible assistance.

(*b*) Get diver to surface properly; support him at surface.

(6) Surface personnel should do the following:

(*a*) Give ample help in getting diver aboard.

(*b*) Provide rest, warmth, and nourishment.

Prevention

(7) Prevention is the most important aspect and should almost always be possible. The diver should do the following:

(*a*) Know his own limits and stay within them.

(*b*) Discontinue dive if it exceeds his powers.

(*c*) Use good gear in good condition.

(*d*) Concentrate on training and experience to help eliminate panic.

(*e*) Employ weights and line when working in strong current.

(*f*) Stop to rest and ventilate before becoming overfatigued.

(*g*) Wear adequate cold-water protection.

1.6.15 SYNCOPE (FAINTING) (see 1.3.3 (15) and app. A)

1.6.16 LOSS OF COMMUNICATION

(1) Loss of contact either between a self-contained diver and his buddy or between a surface-supplied diver and his tender is a potentially serious matter. It can be the first sign of a hazardous mishap, or can sometimes lead to a serious accident.

Causes

(2) In self-contained diving, loss of visual or other means of contact between swim buddies may mean the following:

(*a*) Simple inattention has resulted in separation of the divers and both are all right.

(*b*) One diver has had to surface for some reason and was unable to communicate his departure to the other.

(*c*) One diver is in trouble under water.

(3) In surface-supplied diving, similarly, loss of communication can mean either that the diver has suffered some disabling mishap, or merely that the means of communication have failed. However, if it cannot be clearly shown that it is only a failure of the means of communication, loss of contact must be presumed to mean that the diver has lost consciousness. Appropriate action must then be taken. In this case, it is extremely important that the action involve minimal risk of harming the diver.

Action

(4) If swim buddies lose contact with each other, they must immediately make an attempt to locate each other so that the worst possibilities can be ruled out, or so that necessary action can be taken as soon as possible. Unless one diver will lose an immediate opportunity to locate and assist his buddy if he should surface, he should ascend to the surface and notify the diving supervisor of the situation. If both divers are all right and do this, the diving supervisor will orient them. If one diver is in trouble, the diving supervisor will then be able to muster all available assistance.

(5) In diving with deep-sea rig if *telephone communication* is lost, perform the following:

(*a*) Try *hand signals* at once. (Remember, however, that these can also fail for reasons other than disability of the diver.)

(*b*) Note whether the normal amount of air is coming up from the diver. If circumstances normally permit his bubbles to be seen and they are not seen or if they are not evident in normal quantity, there is a strong indication that the diver is in trouble.

(*c*) Listen for sounds from the diving helmet.

1. If no sounds are heard and bubbles are visible, this is near proof that telephone communication circuit is dead. The *diver may be all right.*

2. If sounds are heard, this does not necessarily mean that the diver can hear the tender's request for reply, but it strongly increases suspicion that the diver is in trouble.

(*d*) Divers frequently work in pairs. A diver already on the scene (at depth) can provide immediate assistance and information, but should not replace the role of the standby diver topside.

(6) If you have indicated that the telephone circuit is dead and you know of a probable reason for temporary failure of hand signals, and if diver's bubbles indicate normal ventilation, some delay to wait for spontaneous communication from the diver may be justifiable. Be sure that the standby diver is ready. Have recompression chamber ready if one is available.

(7) Under most circumstances, it is safer to assume the diver is unconscious or helpless, and initiate proper action without delay.

(*a*) In most cases, the safest procedure is to *send down the standby diver to investigate.*

(*b*) Where use of a standby diver is impossible or is considered unwise, follow this procedure:

1. If depth and time of exposure are such that *decompression is not required*, bring diver directly to surface at a speed not in excess of the normal rate. Be prepared for the possibility of causing blowup and air embolism.

2. If exposure permits *surface decompression* without water stops, bring diver up at normal rate and place him in chamber at once.

3. If depth and duration of exposure require decompression in the water, bring up diver at a normal rate to *first decompression stop required* and repeat efforts to communicate with him. If possible, have standby diver meet him at this stop and evaluate his condition. If communication remains impossible and if the standby diver cannot ascertain that the diver is all right, or cannot assist the diver to a depth where surface decompression can be used, bring diver to the surface at normal rate and place him in recompression chamber immediately. Treat from this point as a case of blowup (1.5.6).

WARNING

The depth-time limits beyond which explosive decompression (blowups, etc.) cannot be treated successfully at 165 feet have not been determined. Most situations can be handled in the water by a standby diver. The relative risk of fatal decompression sickness may outweigh the danger of treatment in the water on dives where the missed decompression would greatly exceed the requirements for surface decompression.

4. If no recompression chamber is available, use standby diver to tend man at stops until decompression is completed.

(*c*) From the outset, the standby diver has the advantage of controlling the victim's air and thus reducing the danger of blowup. In many cases, such as when the diver is also fouled, the presence of a standby diver is essential. In cases of simple asphyxia or carbon dioxide blackout, having the standby diver ventilate the victim's helmet may be all that is required to remedy the situation.

Treatment

(8) Treatment of the diver in situations like those described in preceding paragraphs depends primarily upon the diver's condition when he is brought to the surface. If he remains unconscious, follow the steps given in table 1–29.

Prevention

(9) One of the best means of avoiding loss of contact is to communicate frequently and regularly during the dive. In self-contained diving, this clearly applies to whatever means of communication is being used by swim buddies. In surface-supplied diving, both hand signals and telephone communication should be used at frequent intervals whenever possible. This serves to keep the tender informed of the diver's progress and condition, makes failure of the means of communication or an accident to the diver apparent promptly, and often permits the possible causes of loss of contact to be identified and rectified before a difficult problem develops.

1.6.17 MEDICAL CONDITIONS

(1) Although they are not specifically caused by diving, several medical conditions deserve discussion because of their prevalent occurrence in divers, the possible consequences of these conditions in diving, or both.

Respiratory Infections

(2) Infections such as colds, sore throat, and sinusitis are particularly important in diving for several reasons:

(*a*) They can seriously interfere with equalization of pressure in the middle ear and sinuses.

(*b*) Diving with such an infection can be made worse by causing the spread of infection or further damage to tissues involved.

(*c*) A diver with a respiratory infection is seldom close to peak efficiency either mentally or physically.

(*d*) The exposure to cold and fatigue often involved in diving not only may favor the development of such infections, but may also prevent ideal conditions for recovery.

(3) It is frequently impossible to excuse a man from diving every time he has a slight cold. So long as he feels reasonably well and can equalize pressure without much difficulty (aided if necessary by nose drops or a similar medication), no great harm is likely to result from a dive. However, fewer man-hours will generally be lost in the long run if a man does not dive until he has recovered from a cold.

(4) Chest colds, bronchitis, and other conditions can cause additional problems in diving.

(*a*) Coughing is a problem in scuba diving.

(*b*) Breathing resistance in a man's airways may be abnormally high especially at depth, and his ability to work may be reduced.

(*c*) The risk of air embolism caused by temporary obstruction of an air passage may be considerably increased.

(5) Except in an emergency situation, do not dive a man with fever or other signs of a marked respiratory infection, or who has more than a slight cold that involves the chest. Consult the medical officer in every case where there is any doubt. Make sure that men excused from diving for respiratory infections receive proper treatment, take care of themselves, and do not abuse the exemption. Try to encourage the reporting of these conditions without letting them become too easy an excuse to avoid unpleasant jobs. Disqualify men who have exceptionally frequent infections or who have similar symptoms caused by hay fever or asthma.

External-Ear Infections

(6) Infections of the external-ear canal are particularly prevalent and troublesome in scuba divers operating in warm climates. They can cause great discomfort and loss of many man-hours. The difficulty can be markedly reduced if steps such as these are followed:

(*a*) Routine examination of ears by the medical officer at regular intervals.

(*b*) Removal of excessive earwax when found.

(*c*) Good personal cleanliness; fingers and implements should be kept out of ears.

(*d*) A prophylactic routine such as use of alcohol drops to promote drying of ears after each dive.

(*e*) Prompt reporting to the medical officer when symptoms appear (itching, pain, or crusting of the canal).

(*f*) Adequate treatment with avoidance of diving until the condition has cleared.

(*g*) To detect recurrences of external-ear infections promptly, men who have had the condition should be frequently reexamined.

Skin Conditions

(7) Fungus *infections* such as athlete's foot and "jock itch," and other skin disorders, are among the most frequent and annoying conditions in diving. Warm climate and frequent and prolonged wetness favor their development. If neglected, they can become disabling. Usually, serious difficulty can be avoided by the following procedures:

(*a*) Dry thoroughly as soon as possible after a dive.

(*b*) Avoid unnecessarily prolonged wearing of rubber suits, wet clothing, supporters, and snug-fitting trunks. Keep these articles clean.

(*c*) Pay attention to keeping the feet clean and to drying between the toes.

(*d*) Report to the medical officer or corpsman for treatment without delay when signs of infection develop.

(*e*) Avoid diving until condition is healed, or if infection becomes severe or fails to respond to treatment.

Other Medical Problems

(8) This discussion by no means covers all the diseases and illnesses that can be important in diving. A good working relationship between diving officers and supervisors, the divers, and their medical officer or corpsman is important to insure that any physical or psychological difficulties are reported or otherwise noted at an early stage. A medical officer or corpsman who knows the divers well and enjoys their confidence can contribute much to both morale and safe diving, and his recommendations deserve respect.

1.6.18 TREATMENT OF DIVING ACCIDENTS

Principles

(1) There are very few diving accidents that cannot be treated successfully if the *facilities* and *skill* are available for the following:

(*a*) *Recompression.*

(*b*) *Artificial respiration* (see app. A).

(*c*) *First aid* (see app. A).

(2) Management of the victim of a diving accident seldom requires difficult decisions concerning treatment to be undertaken. The foregoing articles have indicated the treatment for specific accidents, but frequently it is impossible to be sure immediately of the nature of an accident; and often the exact sequence of events is never known. Fortunately, satisfactory treatment usually does not require the diver to know these things or to make an exact diagnosis. It is far more important to take appropriate action than to debate what has happened. The proper action for almost all diving casualties is summed up by the following four simple statements:

(*a*) If the diver is not breathing, give him *artificial respiration.*

(*b*) If there is *any chance* that the diver needs *recompression*, see that he gets it.

(*c*) If the diver is injured, give him *first aid.*

(*d*) Send for a medical officer at once (unless it is a very mild or simple condition.

(3) Remember that a victim of an accident might need all three forms of treatment. The fact that a man is not breathing never proves that he does not need recompression. The same man might also be bleeding severely from an injury. Think of these things and try to provide all the needed forms of treatment as rapidly as possible. If everything cannot be done at once, use your judgment and do your best. Remember that artificial respiration will be useless if the diver bleeds to death from a wound. Recompression will also become useless in a few minutes if no air is getting into his lungs.

(4) Once the proper course of action has been taken, most accident victims will be on their way to recovery if the damage is not too great or the treatment is not too late to permit saving them. During the course of treatment, more difficult decisions or more specialized procedures may be needed. If so a medical officer's help may be urgently needed even in a case which at first appears to be simple. It is therefore advisable to secure medical assistance promptly whenever possible. However, there are few situations when the diver should delay action until a medical officer arrives at the scene, unless the medical officer is already close at hand.

(5) Transportation of an accident victim may be required if the casualty requires recompres-

sion or other treatment that is not available at the scene. Observe these rules wherever possible.

(*a*) If a victim requires artificial respiration alone, do not move him any farther than is essential until normal breathing resumes. Continue artificial respiration by some means during any necessary move. Keep the victim flat for awhile even after he regains consciousness. (Sitting or standing too soon may produce fainting, heart failure, or shock.)

(*b*) If a victim requires *both* artificial respiration and recompression, start artificial respiration and keep it up continuously by some method while transporting him to a recompression chamber. If this is impossible or extremely difficult, concentrate on artificial respiration; but try not to omit or delay either procedure. (See the following paragraph for one possible exception to this rule.)

(*c*) If air embolism appears to be the most probable cause of cessation of breathing and a chamber is *immediately* available, recompress at once and start artificial respiration as soon as the victim is in the chamber.

(*d*) Do not transport a casualty by air except at low altitude or in a pressurized aircraft especially if he is, or may be, suffering from decompression sickness or air embolism. (The reduced pressure of altitude will not only enlarge any bubbles that may be present but will aggravate *any* condition in which hypoxia is a factor.)

(*e*) If oxygen is available, administer it to the patient during transportation. This is *especially important* when using air transportation. (Oxygen administered to the victim will assist in maintaining tissue oxygen levels in almost all conditions, and may cause some reduction in the size of bubbles in case of decompression sickness and air embolism.)

(*f*) Keep any unconscious victim lying down during transportation and guard against airway obstruction. In cases of shock and suspected air embolism, keep the victim's legs elevated.

(6) The following paragraphs present useful information concerning the facilities and skills required for forms of treatment most likely to be needed. Much of the essential information is provided in the form of convenient tables. (See tables 1–32, 1–33, and 1–34.)

Recompression Chamber

(7) Prompt recompression is the only treatment for air embolism and decompression sickness, and recompression in the water is at best a hazardous and difficult procedure—almost always too difficult and too dangerous even to attempt with self-contained equipment. Therefore, a recompression chamber should be close by the scene of any diving operation if this can possibly be arranged. Prior to diving, make sure that the chamber is ready for use. If at all possible, obtain a portable chamber when conducting operations in remote areas. If a chamber cannot be provided at the scene, know the location of the nearest one, provide fast means of reaching it, and be sure that it is ready for use.

(8) Recompression chambers are regularly furnished to ships and activities that do either very deep diving, a large amount of relatively shallow diving, or both. They are required not only for treatment of decompression sickness and air embolism, but also for use in surface decompression and for administering pressure and oxygen tolerance tests.

(9) Two types of chambers are most commonly provided. One is a two-lock chamber having a working pressure of 200 psi (fig. 1–36). The other is a one-lock chamber having a working pressure of 100 psi. Both these types are intended for permanent installation. A less common type which is more readily moved is constructed of aluminum. It has two locks even though it is a much smaller size than the usual two-lock chamber. The working pressure of all these chambers is adequate for recompression in accordance with the treatment tables.

(10) The large recompression chamber has a total volume of about 500 cubic feet—inner lock, 370 cubic feet; outer lock, 130 cubic feet. Such chambers are provided for activities that are required to dive to extreme depths and where resultant cases of decompression sickness are more likely to require prolonged treatment and the assistance of medical personnel. For example, the large chambers are found aboard submarine rescue vessels and submarine tenders. The one-lock chamber has a volume of about 250 cubic feet.

(11) The principal advantage of a two-lock chamber is that personnel are able to enter and

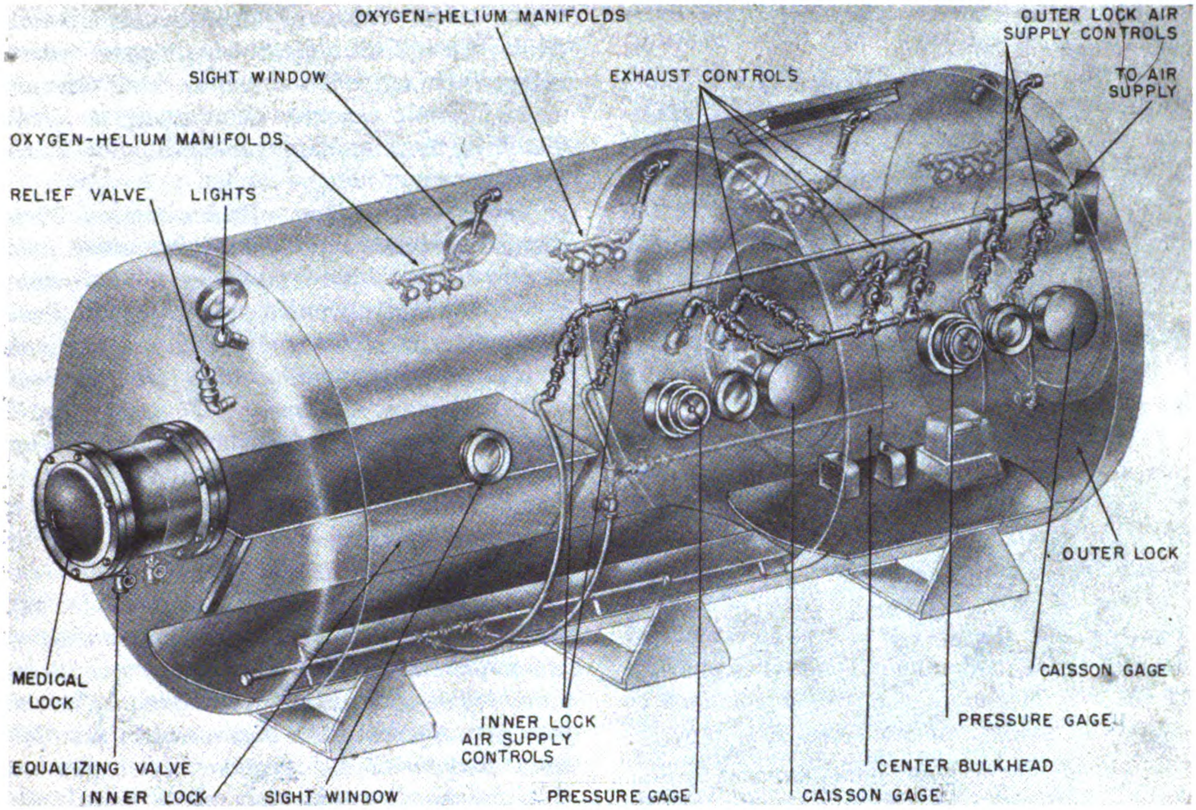

FIGURE 1–36.—Diagram of recompression chamber. Recompression chamber shown is of the type having an inner lock (left) and an outer lock (right). Diver and tender occupy inner lock. When necessary for personnel to enter or leave inner lock, pressure is built up in outer lock so inner chamber door can be opened. Tender leaving inner lock is given proper decompression during ascent in outer lock. Small medical lock at opposite (left) end of chamber is equipped with valves for equalization of pressure and can be used to permit food, medical supplies, and other small articles to be sent into chamber or removed from it.

to leave the chamber during the course of treatment. With a one-lock chamber, the attendant obviously must remain with the patient throughout treatment and cannot be relieved or assisted. All regular chambers are provided with a means of sending food, medical supplies, and other small articles in and out.

(12) Readily portable chambers are not in common use in the Navy, but they are of value to any diving activity that must operate at a distance from a permanent installation. Even a chamber so small that it holds only the patient is far better than no chamber. It provides adequate treatment for the majority of cases of decompression sickness, and permits transportation of the victim rapidly by air without risking further injury (see (5) above). The value of a portable chamber is increased if it allows the patient to be transferred to a larger chamber.

(13) *Air supply for the recompression chamber.*—Satisfactory operation of a chamber requires a large and reliable supply of suitable compressed air.

(*a*) The *volume* of air needed, in terms of free air measured at 1 atmosphere, is equal to the internal volume of the chamber times the number of atmospheres of *increase* in pressure required. For example, it will take $500 \times 5 = 2{,}500$ cubic feet of free air for the usual two-lock chamber at surface pressure to reach a treatment depth pressure at 165 feet (6 atmospheres absolute). The supply should permit taking the chamber to its working pressure, and a generous safety factor should be provided. The supply must also be adequate for ventilation of the chamber for an indefinite period after the desired pressure has been reached, as well as for operation of the outer lock if there is one.

(*b*) The air must be provided at a pressure no less than the working pressure of the chamber. The supply must permit delivery of the required volume of air within a few minutes.

(*c*) The air itself must be free from oil and other foreign matter, and from objectionable gases and odors. It must be as cool as possible.

(*d*) The chamber must not depend upon a single source of air. There *must* always be a standby source that can be used in an emergency.

(14) A satisfactory air supply generally requires a bank of cylinders of ample capacity and at least one reliable compressor. If possible, the supply available in the banks should be sufficient to take the chamber to its working pressure at least twice without additional charging. The compressor should be capable of recharging the banks at a reasonably rapid rate. At the very minimum, the compressor must be capable of pressurizing the chamber to working pressure within a few minutes, and of maintaining adequate ventilation at that pressure. (Note that *direct* use of a compressor is highly undesirable because of the problem of temperature. It is much more satisfactory to use banks or some type of accumulator in which the air can be cooled before it enters the chamber.)

(15) Piping and valves should be arranged to permit control of air supply and exhaust from either the outside or the inside of both locks. However, the system must permit control from the inside to be overridden by control from the outside. The usual arrangement provides one supply line and one exhaust line, each fitted with a single valve outside the chamber. A second set of supply lines and exhaust lines is provided with double valves, one valve on the inside and one valve on the outside. With this arrangement, the tender inside the chamber can regulate descent or ascent, but he is subject to final control by the outside tenders. In addition, it is desirable to provide an extra stop valve on each main supply line and exhaust line to be used in the event of failure of one of the other lines. Optimum chamber ventilation requires maximum separation of the inlet and exhaust ports within the chamber. Providing the inlet port with an effective silencer is worthwhile. Each lock should be equipped with a safety valve set to lift at the working pressure, and of ample capacity to vent air at a rate matching the maximum probable inflow at the pressure.

(16) *Pressure gages.*—Each main lock of the chamber requires a pressure gage (which reads in feet of sea water) mounted on the outside close to the controls, and a caisson gage similarly marked mounted inside. Periodic calibration of all chamber gages is important (see app. B).

(17) *Oxygen equipment.*—To permit use of oxygen during recompression treatment (and for administration of oxygen tolerance tests, if this is anticipated), the inner lock should be equipped with connections for at least three demand-type oxygen inhalators.

(*a*) The exact arrangement required for supplying these connections depends upon the type of equipment used, and whether the activity has a central oxygen-distribution system. The simplest arrangement has a high-pressure manifold for at least two large oxygen cylinders just outside the chamber with stop valves, gage, and a high-pressure line to the inside. A high-pressure manifold is provided inside the chamber with at least two valves and connections like those on standard oxygen cylinders. The usual inhalator (see (*d*) below) is equipped with its own pressure regulator and operates best when connected directly to a high-pressure source without intermediate pressure reduction. Because the regulator is inside the chamber, the demand unit is automatically provided with the proper over-bottom pressure for optimum operation. Replacing oxygen cylinders is the only thing that requires special attention during use of the system. The high-pressure system must be properly constructed, hydrostatically tested, and properly cleaned (see app. B).

(*b*) Provision of a similar system in the outer lock is not required but is occasionally desirable (as in the use of oxygen decompression for tenders leaving the chamber).

(*c*) The desirability of having helium-oxygen mixtures available for use in treatment (table 1–32) warrants making provisions whereby the oxygen inhalation system can be supplied with helium-oxygen. A bleed valve should be provided. Provision of a separate system complete with its own manifold and inhalators inside the chamber is required for 200-psi chambers on helium-oxygen diving ships.

(*d*) The demand inhalators used to administer oxygen or helium-oxygen mixtures should be of the standard type: *Inhalator, Divers', Federal Standard Stock Catalog*, IH 4220–240–7150. Oxygen breathing devices that involve the possibility of rebreathing exhaled gas or of drawing air into the system present serious hazards. They must not be used in the chamber for any purpose.

(18) Ventilation of the recompression chamber during use is necessary not only for the comfort of the occupants (mainly a matter of temperature and humidity) but also for the maintenance of levels of carbon dioxide and oxygen within safe limits. When the air supply is ample, the occupants' demands for ventilation for the sake of comfort are likely to exceed what is needed to keep the gases under control. However, adequate ventilation is always desirable; and when the air supply is limited or the number of men in the chamber is unusually large, proper ventilation becomes critical. It is necessary to know two things: (1) the amount of ventilation needed, and (2) the procedure for providing this amount—how much and how often the valves need to be opened.

(*a*) *Rules for ventilation* are presented in table 1–32. These rules permit rapid computation of the number of cubic feet of air per minute (*as measured at chamber pressure*) required under different conditions. (The rules are designed to assure that the *effective* concentration of carbon dioxide will not exceed 1.5 percent and that when oxygen is being used, the true percentage of oxygen in the chamber will not exceed 25 percent.) If continuous analysis of oxygen is available, the chamber should be ventilated to keep the oxygen percentage below 22.5 percent in order to reduce fire hazard. For example, if the rules call for 4 cubic feet per minute, the chamber can be flushed continuously at a steady rate of 4 cubic feet per minute.

(*b*) *Setting the valves.*—Knowledge of the amount of air that must be used does not solve the ventilation problem unless there is some way to determine the volume of air actually being used for ventilation. One such means would be provided if it were known that opening the exhaust valve a certain number of turns (or fractions of a turn) would give a certain number of cubic feet of ventilation per minute at a certain chamber pressure. It would then be simple to open the exhaust valve that far and to use the control valve to keep up the chamber pressure while the chamber is ventilated for the necessary period of time. Determination of valve settings required for different amounts of ventilation at different depths is not difficult.

1. Mark the valve handle so that it is possible to determine fairly accurately the number of turns and fractions of turns.

2. Check the rules in table 1–32 against probable situations to determine the rates of ventilation at various depths (chamber pressures) that are likely to be needed. If the air supply is ample, determination of ventilation rates for a few depths (30, 60, 100, and 165 feet) may be sufficient, because the valve opening specified for a given rate of flow at one depth will provide at least that much at a deeper depth. It will be convenient to know the valve settings for rates like 30, 60, or 120 cubic feet per minute because these give a simple relationship between volume and time (60 cubic feet per minute=1 cubic foot per second, etc.).

3. Determine the necessary valve settings for the selected flows and depths by using the chamber itself as a measuring vessel with the help of a stopwatch.

(*a*) Calculate how long it would take to change the chamber pressure by 10 feet if the exhaust valve were letting air escape at the desired rate close to the depth in question. Use this formula:

$$T=\frac{V\times 20}{R\times\frac{(P+33)}{33}}$$

where

T=time in seconds for chamber pressure to change 10 feet

V=internal volume of chamber (or of lock being used for test) in cubic feet

R=rate of ventilation desired, in cubic feet per minute as measured at chamber pressure

P=chamber pressure (gage) in feet of sea water.

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Example: How long will it take pressure to drop from 170 to 160 feet in a 500-cubic-foot chamber if the exhaust valve is releasing 60 cubic feet of air per minute (as measured at chamber pressure of 165 feet)?

T=?
V=500 cubic feet
R=60 cubic feet per minute
P=165 feet

Insert values in formula:

$$T=\frac{20\times 500}{\frac{60\times(165+33)}{33}}=\frac{10{,}000}{60\times 6}=27.8 \text{ seconds}$$

(Round to the nearest whole second, here 28.)

(*b*) Take chamber pressure down (with no one inside) to 5 feet beyond the depth in question. Then open the exhaust valve a certain amount and determine how long it takes to come up 10 feet. (For example, if checking for a depth of 165 feet, take chamber pressure to 170 feet and clock the time it takes to reach 160 feet.) Try opening the valve different amounts until you know what setting will give close to the desired time. Write down what the setting is. Calculate times for other rates and depths and determine settings for these in the same way. Make a chart or table of the valve settings found and prepare a ventilation bill using this information and the ventilation rules (table 1–32).

(*c*) *Sample ventilation problems.*

1. Problem 1: the chamber pressure is at 30 feet with the patient and one tender resting, and one tender activity taking care of the patient. All are breathing air. Therefore, the basic ventilation rate is a constant ventilation rate of—

$$2+2+4=8 \text{ cubic feet per minute}$$

2. Problem 2 is the same situation as problem 1, but the constant ventilation rate was interrupted for 5 minutes. Therefore, when ventilation is resumed, it must be at twice the rate for twice the interruption interval:

$$8\times 2=16 \text{ cubic feet per minute for } 2\times 5=10 \text{ minutes}$$

3. Problem 3: the chamber pressure is at 30 feet with the patient and one tender at rest breathing oxygen, and one tender breathing oxygen actively tending the patient. A medical officer is in the chamber but is breathing air. Therefore, the constant ventilation rate required is—

$$12.5+12.5+25=50 \text{ cubic feet per minute}$$

4. Problem 4 is the same situation as problem 3, but the constant ventilation rate was interrupted for 5 minutes. Therefore, when the ventilation rate is resumed it must be at twice the rate for twice the interruption interval:

$$2\times 50=100 \text{ cubic feet per minute for } 2\times 5=10 \text{ minutes}$$

5. Problem 5 is the same situation as problem 3 except that all three of the oxygen-breathing people are using an oxygen elimination system (see app. B). Therefore, the required ventilation rate reverts to that for air with three people resting and one working:

$$2+2+2+4=10 \text{ cubic feet per minute}$$

(*d*) *Notes on chamber ventilation.*

1. The rules given (table 1–32) are not intended to *limit* ventilation. If air is reasonably plentiful, more air than is specified should generally be used for the sake of comfort. This increase is desirable because it also further lowers the concentrations of carbon dioxide and oxygen.

2. There is seldom any danger of having too little oxygen in the chamber. Even with no ventilation and a high carbon dioxide level, the oxygen present would be ample for a long time.

3. The rules given assume that circulation of air in the chamber during ventilation is reasonably good. If it is poor, the rules may be inadequate. Having the inlet near one end of the chamber and the outlet near the other end helps promote good ventilation.

4. Coming up to the next stop helps reduce the gas levels, and proper ventilation requires a smaller actual quantity of air as depth decreases.

5. Constant ventilation is by far the most effective method of ventilation in terms of the amount of air required for ventilation. However, it has the disadvantage of exposing the men in the chamber to a constant source of noise. At the very high ventilation rates required for oxygen breathing (table 1–32), this noise can reach the ranges where hearing loss becomes a real hazard to the men in the chamber. Some chambers have adequate baffle systems within their air-supply systems to reduce noise to a minimum. If high sound levels do occur, especially during exceptionally high ventilation rates, the men in the chamber should be required to wear ear protectors similar to those used in aviation on flight decks. Such ear protection is adequately afforded by a readily available stock item: Aural Protector, Federal Stock No. 2RD–4240–759–3290–LF50. The only modification which these items require is a small hole drilled into the central cavity so that they do not produce an ear seal which could cause an ear squeeze. The use of an oxygen-elimination system would greatly reduce the noise problem.

6. Note that the size of the chamber does not influence the amount of air required for ventilation.

7. Note also that increasing depth increases the actual mass of air required for ventilation; but when the amount of air is expressed in volumes as measured at chamber pressure, increasing depth does not change the number of cubic feet required.

(19) *Communication equipment.*—It is extremely important to insure good voice communication between the inside and outside of both locks of the chamber. The primary system should be an intercom with speakers that double as microphones, arranged so that personnel inside the chamber can hear and be heard in normal voices without interrupting their activities. This type of system can be provided by the standard divers' amplifier. It is also extremely desirable to have a second system of some kind as a standby for emergency use. The simplest and most infallible standby is provided by a set of sound-powered telephones. All voice communication gear should be carefully maintained and checked at weekly intervals.

(20) *Electrical equipment.*—The wiring of a recompression chamber must be of an approved heavy-duty type, armored or in conduit. All electrical switches should be located outside the chamber. All lighting fixtures should be permanently installed; and if they are not of the pressureproof type, they must at least be provided with heavy glass covers for the bulbs. (Fluorescent fixtures must not be used.) If appliance receptacles are provided, these must be of a type that insures positive contact and no chance of accidental removal of the appliance plug. Household-type electrical outlets and connections, and jury rigs of any kind, must *absolutely never* be used.

(*a*) It is a good policy to prohibit all electrical equipment other than lights. Heat may be safely provided by a small steam line and radiator.

(*b*) If the wiring provides the necessary separate circuit, one desirable addition is a low-intensity light that can be used to relieve the patient of the heat and glare of the regular lights, yet permit him to be continuously observed during long treatment. (This can also be provided by a portable light placed outside of one of the ports.)

(*c*) All electrical wiring and equipment must be checked at regular intervals and kept in perfect condition.

Precautions in Use of Chamber

(21) The chamber itself must be kept in an optimum state of repair and subjected to periodic test (table 1–34). Periodic training runs should be made to insure proper operation and readiness of the chamber and all its accessory equipment, as well as to keep personnel familiar with its use. Appropriate periodic checks and preventive maintenance routines should be applied to the air supply, oxygen and helium-oxygen systems, and the communication and electrical equipment. The chamber must never be used for stowage of gear, as a locker, or for sleeping quarters.

(22) Certain features of operation deserve special comment:

(*a*) Unless doors are sprung or gaskets improperly fitted, only enough force to make an initial seal is required on hatch dogs. As pressure builds up in the chamber, the seal automatically becomes tighter and tighter. Dogs should be released routinely as soon as pressure is adequate to hold. They should be rechecked before pressure is reduced to make sure they have been released.

(*b*) *Explosive fire* is the most serious danger in operation of a recompression chamber. The danger is ever present and is increased at pressure and when pure oxygen enters the chamber in the course of oxygen breathing in treatment. In both cases, the effective concentration (partial pressure) of oxygen is increased. To reduce the possibility of fire, the following precautions must be taken:

1. Replace all wooden deck gratings, benches, shelving, etc., with metal or other fireproof material.

2. Use only fire-retarding paint similar to that listed in the Federal Standard Stock Catalog (GF-8010-290-2875), and keep painting to the absolute minimum—one coat of preservative and one coat of white. If it is not known whether the chamber has been painted in this manner, remove all old paint and repaint as indicated. Insure that thorough drying of paint and removing of all volatile vapors by ventilation is accomplished before using the chamber.

3. Be certain that the electrical system complies with (20), above.

4. Keep the interior of the chamber free of all dirt and refuse and any oily deposits or volatile materials of any kind. If for any reason flammable liquids such as ether, alcohol, gasoline, or volatile oils, or their vapors, have been present, thorough ventilation must precede use of the chamber. No oils should be in or on high-pressure lines or apparatus of the oxygen-breathing installation. Allow no oils or volatile materials to collect or soak into any absorbent material in the chamber or in the well under the deck plates. All air filters and accumulators in lines leading to the chamber must be cleaned regularly to keep oil and vapors from being carried in.

5. If a mattress is used, insure that it is covered by fire-resistant sheeting on all sides. Keep blankets and other bedding to the minimum required for the patient's comfort. Do not use wool or synthetic-fiber blankets because of the possibility of sparks from static electricity. Flameproof bedding material can be obtained from the Naval Supply Center, Oakland, or the Naval Supply Depot, Bayonne, under Stock No. GF-7210-243-8863 or GF-7210-243-8864. Clothing worn by personnel in the chamber must be free from grease or oil.

6. No open flames, matches, cigarette lighters, lighted cigarettes, cigars, or pipes are to be taken in or used in the chamber at any time.

7. When oxygen is being used, the chamber must be ventilated *at least* to the extent specified in table 1-32. Have water and sand buckets on hand in the chamber during use of oxygen. Carbon tetrachloride fire extinguishers must *never* be used.

8. Use no electrical appliance of any kind (other than lights) in the chamber during oxygen breathing. Ventilate thoroughly following oxygen breathing before any appliance is turned on.

9. Post a warning, like that in table 1-34, prominently inside and outside the chamber.

10. If the above precautions are taken, the possibility of fire within the chamber will be reduced.

Treatment by Recompression

(23) Actual use of the recompression chamber for treatment of decompression sickness and air embolism is covered in the treatment tables (tables 1-30 and 1-31) and in the additional table of notes on recompression (table 1-32). Only medical officers trained in the management of diving accidents are permitted to modify the procedures specified, except in case of acute emergency or obvious necessity.

(24) Conduct of treatment requires accurate timekeeping and recording of all significant events and other information, as well as competent operation of the chamber and provision of tenders. Do not neglect to fill in form NAVMED 6420/1 (Rev. 3-67) promptly for each patient treated (1.87).

Preparedness

(25) The personnel and facilities of all diving activities must be prepared at all times to provide treatment of decompression sickness or air embolism at a moment's notice. Because of the possibility of being called to treat a commercial or sport diver, readiness is required even if the activity itself has not made dives recently. The state of readiness should be such that the minimum number of personnel aboard at any time can at least begin treatment without assistance and without delay.

(*a*) Keep the chamber itself ready for immediate use.

(*b*) If air banks are available, keep them charged sufficiently to take the chamber to 165 feet. Keep the compressor ready to operate.

(*c*) Be sure that oxygen equipment is ready, demand inhalators operable, and supply cylinders full.

(*d*) Keep communication equipment ready to turn on and use.

(*e*) Be sure stopwatches are at hand and that all items that may be required in the chamber are either in it or immediately available. Such items include:

1. Emergency medical kit and related equipment (see (30) below).

2. Slate and chalk or pencil and paper.

3. Wingnut wrench.

4. Fire-resistant mattress and blankets.

5. Bucket and plastic bags for body wastes.

6. Water and sand buckets.

(*f*) Insure that all personnel have been thoroughly instructed in the use of the chamber and its auxiliary equipment and that any man can take any station required in its operation. Maintain readiness through periodic training runs directed by the medical or diving officer.

(*g*) Have a casualty bill in force that defines stations and assigns specific tasks to all personnel required in the operation of the chamber. These include, for example:

1. Two "outside tenders" to operate supply and exhaust valves of inner and outer locks.

2. Timekeeper.

3. Talker.

4. Recorder.

5. Personnel required to operate air banks and compressor.

(Note that some jobs can be combined if necessary, but that the duties of each must be defined clearly.)

(26) Preparedness for handling casualties extends also to the ability to provide artificial respiration, first aid, and other measures that may be required in addition to—or instead of—recompression. The more important considerations in preparedness are summarized in table 1–34.

Artificial Respiration

(27) Appendix A provides necessary information concerning *manual artificial respiration* in ready-reference form. All hands should be instructed in the mouth-to-mouth method and should be given an opportunity to practice it on simulated "victims." All hands should at least be aware of the alternative methods and, if the circumstances of their work make the necessity of using them likely, should be trained in them also. Drills with the mechanical resuscitator should also be provided.

Emergency Medical Supplies

(28) The number and variety of emergencies that can arise in diving require that a considerable number of items of medical equipment and supplies be available for prompt use by the medical officer or corpsman. What must be kept immediately at hand for first-aid and subsequent treatment depends somewhat on the availability of such items from the ship's regular sickbay or from a dispensary or hospital close to a shore-based diving activity. The possible needs and means of filing them should be considered carefully and appropriate steps taken by the medical officer or corpsman responsible.

(29) Every diving activity should *maintain* an emergency kit which can be available immediately at the scene of a diving accident or in the recompression chamber. The kit should be small enough to carry into the chamber immediately. Because many sterile items must be considered contaminated after exposure to increased atmospheric pressure, it is desirable to have a primary and a secondary emergency kit:

(*a*) Kit No. 1—Primary Emergency Kit: Diagnostic equipment needed routinely, and equipment most likely to be needed immediately.

(*b*) Kit No. 2—Secondary Emergency Kit: Equipment and medicines that might be needed, but that can be sent into the chamber if specifically called for.

(30) *Suggested contents of emergency kits:*

(*a*) Kit No. 1: Diagnostic equipment routinely useful:

1. Flashlight

2. Stethoscope

3. Otoscope-ophthalmoscope

4. Sphygmomanometer (aneroid type, *never* mercury)

5. Reflex hammer

6. Tuning fork

7. Pin and brush for sensory testing

8. Tongue depressors

Emergency treatment equipment and medications:

1. Tongue depressors taped and padded as a bite pad for use in case of convulsions

2. Oropharyngeal airway

3. Rubber tubes equivalent to sizes 4 and 6 for temporary use in a tracheotomy, with a safety pin through that end to be kept outside the trachea.

4. Sterile scalpel and blade assortment

5. Sterile hemostats (two each)

6. 5-cc syringe (two each) with needles

7. Bandage scissors

8. Spirits of ammonia capsules

9. Epinephrine 1:1,000 aqueous for injection

10. Aramine or a similar pressor agent

11. Sterile gauze pads

12. Cotton balls

13. Benzalkonium chloride

Miscellaneous:

1. Adhesive tape

2. Tourniquet

(*b*) Kit No. 2: Emergency equipment:

1. Suture material, sterile

2. Suture needles, assorted, sterile

3. Sterile syringes:

a. 5 cc, 2 each

b. 10 cc, 2 each

c. 30 cc, 2 each

4. Sterile needles, 16, 18, 20, and 22 gage, preferably disposable

5. Three-way stopcocks, sterile, 2 each

6. Sterile thoracentesis needle, 16 gage, 4″ long

7. Sterile intracardiac needle

8. Sterile rubber tube for endotracheal suction (a soft-tip tube causes less damage to the trachea)

Emergency medications:

1. Intravenous fluids:

a. 5 percent dextrose in saline

b. 5 percent dextrose in water

2. Procaine, 1 percent (if possible, one with and one without epinephrine)

3. Soluble steroid for intravenous or intramuscular injection (e.g., Solu-Medrol, Solu-Cortef)

4. Amytal sodium (amobarbital sodium) injectable

5. Phenobarbital injectable

6. Dilantin, injectable

7. Thorazine, injectable or suppositories

8. An injectable antihistamine

9. Sterile water for injection

10. Boric acid, 2 percent ophthalmic solution

11. Tincture of merthiolate

Miscellaneous:

1. Nasogastric tube

2. Asepto syringe

3. Sterile bladder catheterization tray (preferably disposable)

4. Intravenous infusion kits, sterile, disposable (two each)

5. Gauze roller bandage, 1″ and 2″, sterile

6. Gauze sponges, 4″ by 4″, sterile

7. Band-Aids

8. Sterile gloves, surgical

9. Sterile towels

10. Splints

11. Aspirator suitable for safe use inside the chamber

12. Eye patch

(31) *Comments on contents of emergency kit:*

(*a*) The sterile supplies, if not adequately sealed against the increased atmospheric pressure, should be resterilized after each pressure exposure, or, if not exposed, at 6-month intervals.

Not all drug ampules will withstand pressure, and bottle stoppers may be pushed in. Bottles with stoppers may be vented with a needle just prior to pressurization, and then discarded if not used.

(*b*) Because the available facilities may differ on board ship, at land-based diving installations, and at diver-training or experimental units, the responsible medical officer or hospital man will have to modify the emergency kits to suit the local needs. Both kits should be taken to the recompression chamber or scene of the accident. The responsible doctor or hospital man then can decide whether he needs kit No. 1 only, both kits, or kit No. 1 plus certain items from kit No. 2. In a case of minor, uncomplicated extremity pain, for example, it would not be necessary to contaminate all of kit No. 2. When in doubt, or if the second kit cannot be locked in readily once the chamber is at pressure, take both kits to pressure.

(*c*) Several items have multiple use. For example, the 30-cc syringe could be used with the endotracheal catheter for aspiration of secretions from the throat until a more effective aspirator could be provided; or it could be used with the thoracentesis needle for aspirating air from the chest in a massive pneumothorax requiring immediate relief.

(32) The emergency kit should be *sealed* in such a way that it can be opened readily when needed but will not be opened and plundered for no good cause. A broken seal will indicate that it has been opened. The kit should contain a list of contents, and each time it is opened (or at monthly intervals in any case), it should be checked for presence and condition of all items. Sterile supplies should be provided in duplicate so that one set can be autoclaved in the meantime.

(33) By and large, use of the emergency kit should be restricted to the medical officer or a well-trained corpsman. Concise instructions for administration of each drug should be provided in the kit. In untrained hands, many of the items can be dangerous. Remember that, as in all types of treatment, YOUR FIRST DUTY IS NOT TO DO HARM.

SECTION 1.7 GENERAL SAFETY PRECAUTIONS

1.7.1 GENERAL

(1) Each type of diving equipment and *operation* gives rise to unique demands for safety precautions. The safety precautions presented in this section are those common to all diving. This part of the manual is intended to be used as a check-off list by those responsible for safety in diving.

1.7.2 ADMINISTRATION AND PLANNING

(1) Have you notified all interested activities that diving operations are in progress?

(2) Is the type of gear you have chosen to use adequate and safe for the job?

(3) Is the recompression chamber ready for use, or have you notified the nearest command having one that you may need it?

(4) Have you made provision to obtain medical assistance in case of emergency?

(5) Has a competent diving supervisor been designated to be in charge of the job?

(6) Has a timekeeper been detailed and does he understand his duties and responsibilities?

(7) Have you a copy of the decompression tables available?

(8) Have the divers been thoroughly briefed and do they understand what is to be accomplished and how?

(9) Has a lead line or pneumofathometer measurement of the depth of water been made?

(10) If conducting a search, have you exhausted all other means before putting the divers down?

(11) If diving involves the propeller of a ship, have you informed the duty engineer and received an acknowledgment?

(12) If diving involves the hull of a submarine, have you notified the duty officer not to operate bow planes, stern planes, vents, sound heads, or propellers?

1.7.3 PERSONNEL

(1) Have you determined that all the divers you intend to use have been examined and found to meet the physical standards for deep-sea diving within the current calendar year?

(2) Have all your men been trained to use the equipment you have selected?

(3) Have you reason to suspect the physical condition of any of your men? Consider the following:

(*a*) Do not dive a man if he is suffering from a severe cold, sinusitis, or ear trouble.

(*b*) Do not dive a man who is fatigued from lack of sleep or previous physical or emotional strain.

(*c*) Do not dive a man who shows evidence of alcoholic intoxication or its aftereffects.

(*d*) If you question the physical condition of any man, have him report to the medical officer and be guided by his advice.

(4) Have all the divers been qualified to the depth of the job?

(5) Do not force or urge a man to dive if he honestly desires to be excused. If his reasons for wishing to be excused do not appear to be sufficient or appropriate, it is best to take administrative action.

1.7.4 EQUIPMENT

(1) Has the equipment you intend to use been tested and adopted for Navy use?

(2) Have you inspected the equipment to determine that it is in usable condition?

(3) Have you an adequate supply of compressed gas available?

1.7.5 SAFETY DURING DIVING OPERATIONS

(1) Have all efforts been made to prevent the divers from becoming fouled on the bottom?

(2) Have divers been instructed not to cut any lines until they have made certain of the purpose for which they are being used?

(3) Is the diving boat moored in the most advantageous position to minimize effort by the divers to reach their work?

(4) Are you displaying the proper signal? Refer to appropriate International/Inland Rules, International/Inland Local Signals, and related Navy communications instructions for proper signals to be displayed while conducting underwater operations, in a moor, etc.

(5) Has a standby diver been designated, and is he ready to enter the water in minimum time?

(6) If work is being performed inside a wreck, have you made arrangements for one diver to tend the lines of the diver working inside from the point of entry?

(7) If explosives are being used, have you taken measures to prevent a charge being set off when a diver is in the water?

(8) If electric power for underwater welding or cutting is being used, are you using the full deep-sea diving outfit?

(9) REMEMBER: In all cases, the depth of the water and the condition of the diver, especially with regard to fatigue, rather than the amount of work to be done shall determine the amount of time the diver is to spend on the bottom.

(10) Have you made provisions for decompressing the divers, should this be necessary?

(11) When diving is conducted from a small boat to a depth of 120 feet or greater, an adequate standby air supply is mandatory.

(12) When diving is conducted from a small boat to a depth of 120 feet or greater, a standby diving boat is required at the scene.

1.7.6 RECOMPRESSION CHAMBERS

(1) The following general *safety precautions* must be observed with regard to recompression chambers (table 1–34).

(*a*) The recompression chamber must never be used for a storage space. Keep it clear, clean, and ready for use at all times.

(*b*) Medical supplies as outlined in section 1.6.18(30) must be available at all times.

(*c*) Use only fire-retarding paint inside the chamber.

(*d*) Do not take open flames, cigarette lighters, matches, lighted cigarettes, or pipes into the chamber while it is being used.

(*e*) Decompression tables and treatment tables must be located both on the inside and outside of the chamber.

(*f*) Use fire-resistant nonstatic blankets.

(*g*) Insure that the wrench for the medical lock is inside the chamber.

1.7.7 GENERAL SAFETY RULES GOVERNING THE USE OF COMPRESSED-GAS CYLINDERS AND GASES

(1) In diving, the following compressed gases are commonly used: compressed air, helium, oxygen, and mixtures of these gases. The safety rules contained in this section have been abstracted from NAVSHIPS 0901–923–0000, chapter 9230 (Industrial Gases).

Handling of Cylinders

(2) The following are general safety rules for working with compressed-gas cylinders:

(*a*) Never drop cylinders, or permit them to strike each other violently.

(*b*) Never use a lifting magnet or sling when handling cylinders.

(*c*) Securely close valves and replace valve-cover caps before moving, storing, or returning cylinders.

(*d*) Insure that all cylinders used are approved under Interstate Commerce Commission regulations.

(*e*) Do not fill any cylinder with a gas other than that for which the cylinder was designated, with the exception of nitrogen-oxygen and helium-oxygen mixtures which shall be made up in the inert-gas cylinders (not in O_2 cylinders). Cylinders containing mixed gas will be tagged conspicuously.

(*f*) Never use cylinders for rollers, supports, or any purpose other than to carry gas.

(*g*) Do not tamper with the safety devices or valves on cylinders.

(*h*) Never hammer or strike the valve wheel in attempting to open or close valves. Use only wrenches or tools provided and approved for this purpose.

(*i*) Insure that the threads on regulators or other auxiliary equipment are the same as those on cylinder valve outlets. Never force connections that do not fit.

(*j*) Do not subject compressed-gas cylinders either in storage or service to a temperature in excess of 130° F.

(*k*) Protect cylinders from objects that will produce a cut or other abrasion on the surface of the metal.

(*l*) Do not use any cylinder which is improperly marked.

(*m*) Keep compartments where compressed gases are stored (or in use) well ventilated. Prohibit smoking in such compartments.

(*n*) If valve outlets become clogged with ice, use warm, not boiling, water to thaw them. The use of boiling water will melt the fusible plugs (if present) and vent the cylinder.

(*o*) Never use cylinders that show evidence of damage—for example, cylinders that are severely dented or gouged, bulged from internal pressure, or corroded.

Oxygen and Compressed Air

(3) The following are *safety rules* for working with high concentrations of oxygen:

(*a*) Never permit oil, grease, or other readily combustible substances to come in contact with oxygen cylinders, valves, regulators, gages, and fittings.

(*b*) Never lubricate oxygen or compressed-air valves, regulators, gages, or fittings with oil or other flammable substances.

(*c*) Be sure that all oxygen distribution systems have been *cleaned for oxygen service* in accordance with the Ship Systems Command approved method (see app. B, sec. I) to remove all dirt, filings, grease, oil, and other foreign materials. Repeat the cleaning process whenever contamination of the system (as by oily compressed air, for example) is known to have occurred or is suspected.

(*d*) Never use oxygen from a cylinder without reducing the pressure through a suitable regulator.

(*e*) Use only approved regulators, hose, and other appliances.

(*f*) Never use compressed gases for cooling the body or for blowing dust from clothing. The danger of combustion is great.

(*g*) Do not smoke where oxygen is stored or in use.

Nitrogen-Oxygen Mixtures

(4) Never mix oil-contaminated air with oxygen to obtain a specific nitrogen-oxygen mixture. Handle nitrogen-oxygen and helium-oxygen mixtures according to the same *rules* applied to oxygen.

SECTION 1.8 REPORTS

1.8.1 INTRODUCTION

(1) The reports and records outlined herein are designed to overcome certain inadequacies in the method of logging diving operations. On the assumption that the diver is the most immediately concerned with his own career, the responsibility for preparation of most of the records is placed on him. The responsibility for a high overall standard of completeness and accuracy rests progressively on the diving supervisor, the diving officer, and the personnel and commanding officers.

1.8.2 DIVING RECORD SYSTEM

(1) There are three objectives to be attained in the establishment of an adequate diving record system. These objectives are:

(*a*) Establish a satisfactory operational record.

(*b*) Provide data for analysis.

(*c*) Establish a personal record.

(2) The operational record may be described as a standardized record prepared in accordance with established military practice. Such a record is the normal minimum required when life is risked. It tends to insure proper operational procedures and promotes safety and safe practices.

(3) The second objective is to provide data for analysis. Without knowledge of the type and extent of diving being done in the Navy, it is impossible to estimate accurately the incidence of equipment failure and diving accidents, or to keep abreast of the needed procedures, training, and equipment to meet fleet diving requirements.

(4) The establishment of a personal record in the third objective is an effort to promote esprit de corps and personal pride. By imposing a certain responsibility on the individual, he becomes more aware of the existence of the record and of the benefit of a good record. The long, arduous, unrewarded dives amass an experience level that is, in itself, rewarding. The diving supervisor and diving officer are provided with an assessment factor to assist in the assignment of difficult diving jobs.

1.8.3 COMPONENTS OF THE SYSTEM

(1) The components established to meet the objective outlined above are:

(*a*) Diving Log Book, NAVSHIPS 9940/1 (Rev. 2–67); figures 1–37(*a*) and 1–37(*b*) are sample pages.

(*b*) Diving Duty Summary form (fig. 1–38).

(*c*) Report of Decompression Sickness and All Diving Accidents (NAVMED 6420/1 (Rev. 3–67) (figs. 1–39(*a*) and 1–39(*b*)).

1.8.4 DIVING LOG BOOK

Description

(1) The Diving Log Book, NAVSHIPS 9940/1 (Rev. 2–67), is a looseleaf book of individual dive sheets. It provides a continuous and permanent record of all U.S. Navy diving. Its maintenance by naval commands authorized to conduct diving operations is mandatory.

Purpose

(2) The purpose of the Diving Log Book is primarily to establish a satisfactory and permanent record of diving operations and secondarily to provide data for subsequent analysis.

The first purpose tends to insure proper and safe operational practices. The second purpose enables the Experimental Diving Unit to maintain a final and overall survey of naval diving to better carry out its mission of development and improvement of diving procedures.

Maintenance

(3) To obtain full benefit from this log and to maintain it properly, the diving supervisor must record entries as they occur at the scene of diving operations. These entries should be marked legibly with a *No. 2 lead pencil.* If required by the number of diving locations, by clerical requirements, or other valid reason,

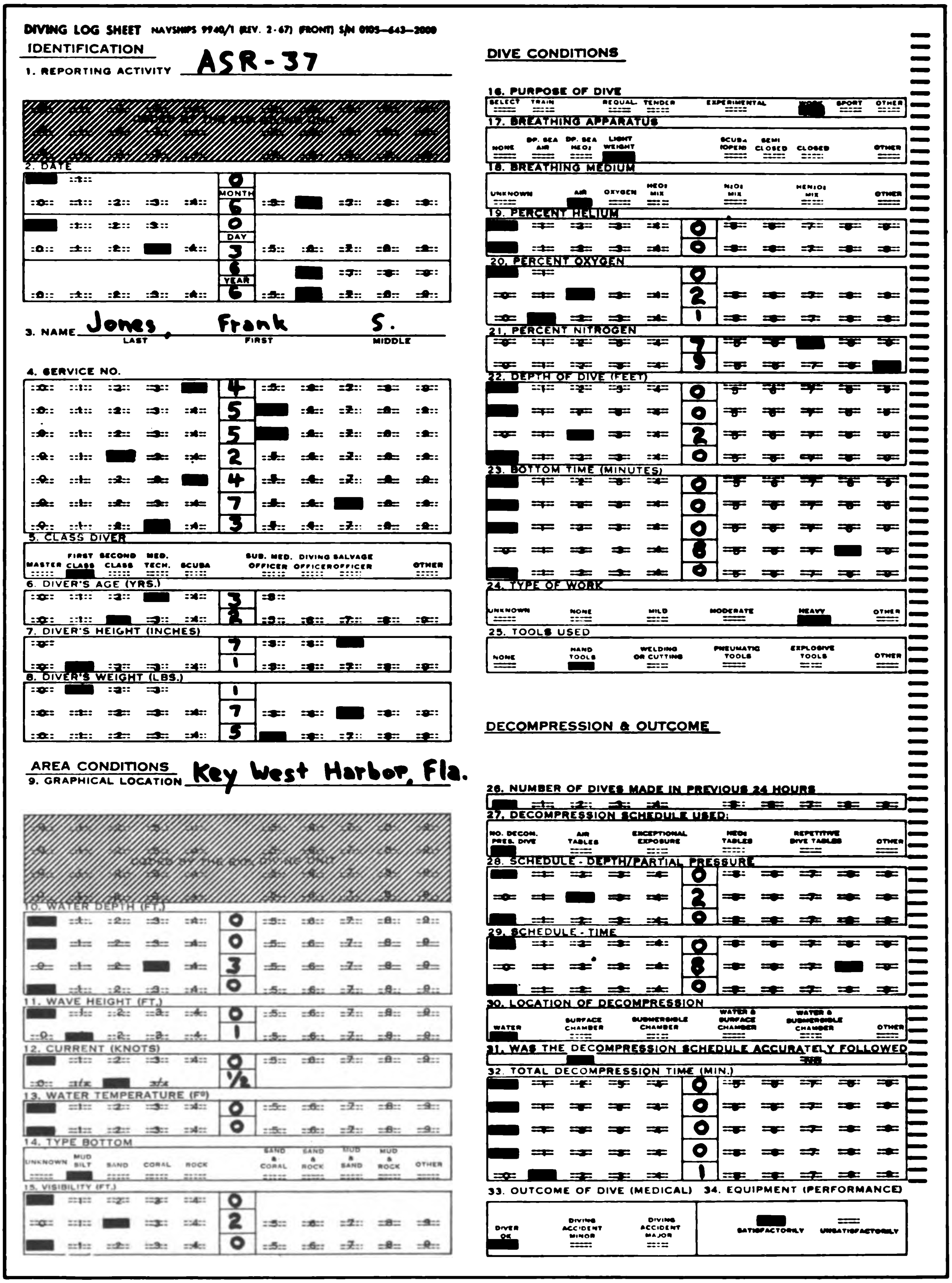

FIGURE 1-37(a).—Diving log sheet. Side 1 (sample page).

35. DECOMPRESSION STOPS

DEPTH	TIME	GAS
20-0	.3 min.	Air

36. JOB DESCRIPTION

Change screw on Quillback SS424
Job complete.

37. ADDITIONAL REMARKS

None

38. SIGNATURES

Bill Hogan — DIVING SUPERVISOR

Jon Smart — DIVING OFFICER

FIGURE 1-37(b).—Diving log sheet. Side 2 (sample page).

DIVING DUTY SUMMARY

QUALIFICATIONS	DATE	CERTIFYING OFFICER	DIVER'S LOG BINDER ISSUED
SCUBA DIVER			ACTIVITY
DIVER SECOND CLASS			DATE
SALVAGE DIVER			DUPLICATE BINDER ISSUED
DEEP SEA DIVER			ACTIVITY
DIVER FIRST CLASS			DATE
MASTER DIVER		AUTHORITY BUPERS LTR. SERIAL OF	REASON

ASSIGNED TO DIVING DUTY		TOTAL DIVES							DETACHED	
		DEEP SEA		LIGHT-WEIGHT	SCUBA					
SHIP OR STATION	DATE	AIR	HEO2		AIR	O2	N_2 O_2	HEO2	DATE	CERT. OFFICER

FORM COMPLETED AND FORWARD TO US NAVAL SCHOOL DEEP SEA DIVERS

C.O. SIGNATURE ______ DATE ______

☐ ON SEPARATION FROM SERVICE

☐ QUALIFICATION REVOKED (GIVE REASON)

DIVER'S NAME (LAST, FIRST, MIDDLE)	SERVICE NO	RANK OR RATE	BRANCH & CLASS

FIGURE 1-38.—Diving duty summary (form).

REPORT OF DECOMPRESSION SICKNESS AND ALL DIVING ACCIDENTS
NAVMED 6420/1 (REV. 3-67)
S/N-0105-214-1650

REPORTS SYMBOL: MED-6420-1

ORIGINAL – BUMED, WASHINGTON, D. C.
COPY – NAVY EXP. DIVING UNIT, WASHINGTON NAVY YARD, WASHINGTON, D. C.
COPY – NAVAL SUB. MED. CENTER, NAVAL SUB. BASE NEW LONDON, GROTON, CONN.

NAME AND ADDRESS OF REPORTING STATION			DATE
NAME OF PATIENT *(Surname first)*	GRADE/RATE	IDENTIFICATION NO.	TYPE OF DIVING ACCIDENT

AGE	WEIGHT	HEIGHT	BUILD *(Check one)*				DIVING QUALIFICATIONS *(Check one)*									
			SLENDER	MED.	HEAVY	OBESE	MAST	1/C	SAL.	D.S.	2/C	UDT	EOD	UWS	STU	(OTHER)
YRS.	LBS.	INS.														

RECORD OF ALL DIVES MADE DURING THE TWELVE HOURS PRECEDING THE ACCIDENT
(If more than three dives were made, record additional under "REMARKS" on reverse.)

FIRST DIVE

TYPE OF DIVE		DEPTH OF DIVE	BOTTOM TIME
WET	DRY	feet	min.

TYPE OF EQUIPMENT

DEEP SEA	DEEP SEA HELIUM	OPEN CIRCUIT SCUBA	CLOSED CIRCUIT SCUBA	SHALLOW WATER MASK	OTHER

TYPE OF WORK

NONE	MILD	MODERATE	HEAVY

BREATHING MEDIUM

AIR	HELIUM % OXYGEN %	OXYGEN	OTHER *(Specify)*

SOURCE OF BREATHING MEDIUM

AIR BANKS	HELIUM-OXYGEN BANKS	GASOLINE COMPRESSOR	OTHER

DECOMPRESSION SCHEDULE

STANDARD	SURFACE USING		HE. DECOMPR.	TABLE USED
	AIR	OXYGEN	P.P.	MIN.
TIME LEFT SURFACE	TIME REACHED BOTTOM		RATE OF ASCENT TO FIRST STOP FT/MIN	TIME REACHED SURFACE

If surface decompression used, time from last water stop to 1st chamber stop. MIN.

SECOND DIVE

TYPE OF DIVE		DEPTH OF DIVE	BOTTOM TIME
WET	DRY	feet	min.

TYPE OF EQUIPMENT

DEEP SEA	DEEP SEA HELIUM	OPEN CIRCUIT SCUBA	CLOSED CIRCUIT SCUBA	SHALLOW WATER MASK	OTHER

TYPE OF WORK

NONE	MILD	MODERATE	HEAVY

BREATHING MEDIUM

AIR	HELIUM % OXYGEN %	OXYGEN	OTHER *(Specify)*

SOURCE OF BREATHING MEDIUM

AIR BANKS	HELIUM-OXYGEN BANKS	GASOLINE COMPRESSOR	OTHER

DECOMPRESSION SCHEDULE

STANDARD	SURFACE USING		HE. DECOMPR.	TABLE USED
	AIR	OXYGEN	P.P.	MIN.
TIME LEFT SURFACE	TIME REACHED BOTTOM		RATE OF ASCENT TO FIRST STOP FT/MIN	TIME REACHED SURFACE

If surface decompression used, time from last water stop to 1st chamber stop. MIN.

THIRD DIVE

TYPE OF DIVE		DEPTH OF DIVE	BOTTOM TIME
WET	DRY	feet	min.

TYPE OF EQUIPMENT

DEEP SEA	DEEP SEA HELIUM	OPEN CIRCUIT SCUBA	CLOSED CIRCUIT SCUBA	SHALLOW WATER MASK	OTHER

TYPE OF WORK

NONE	MILD	MODERATE	HEAVY

BREATHING MEDIUM

AIR	HELIUM % OXYGEN %	OXYGEN	OTHER *(Specify)*

SOURCE OF BREATHING MEDIUM

AIR BANKS	HELIUM-OXYGEN BANKS	GASOLINE COMPRESSOR	OTHER

DECOMPRESSION SCHEDULE

STANDARD	SURFACE USING		HE. DECOMPR.	TABLE USED
	AIR	OXYGEN	P.P.	MIN.
TIME LEFT SURFACE	TIME REACHED BOTTOM		RATE OF ASCENT TO FIRST STOP FT/MIN	TIME REACHED SURFACE

If surface decompression used, time from last water stop to 1st chamber stop. MIN.

Stops (First Dive / Second Dive / Third Dive)

DEPTH OF STOP *(feet)*	WATER: MINUTES AT STOP	WATER: BREATHING MEDIUM	CHAMBER: MINUTES AT STOP	CHAMBER: BREATHING MEDIUM	DEPTH OF STOP *(feet)*	WATER: MINUTES AT STOP	WATER: BREATHING MEDIUM	CHAMBER: MINUTES AT STOP	CHAMBER: BREATHING MEDIUM	DEPTH OF STOP *(feet)*	WATER: MINUTES AT STOP	WATER: BREATHING MEDIUM	CHAMBER: MINUTES AT STOP	CHAMBER: BREATHING MEDIUM
210					210					210				
200					200					200				
190					190					190				
180					180					180				
170					170					170				
160					160					160				
150					150					150				
140					140					140				
130					130					130				
120					120					120				
110					110					110				
100					100					100				
90					90					90				
80					80					80				
70					70					70				
60					60					60				
50					50					50				
40					40					40				
30					30					30				
20					20					20				
10					10					10				

(over)

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Figure 1–39(a).—Report of decompression sickness and all diving accidents. Side 1 (form).

SIGNS AND SYMPTONS BEFORE TREATMENT

	ONSET		ANATOMICAL LOCATION	INTENSITY (MILD, MOD., SEVERE)
	DATE	TIME		
LOCALIZED PAIN				
RASH				
MUSCULAR WEAKNESS				
NUMBNESS				
DIZZINESS				
VISUAL DISTURBANCES				
PARALYSIS				
UNCONSCIOUSNESS				
DYSPNEA (CHOKES)				
NAUSEA OR VOMITING				
MUSCULAR TWITCHING				
RESTLESSNESS				
CONVULSIONS				
ACOUSTIC AURA				
PARESTHESIA				

REMARKS: *(other signs and symptoms before, during and following treatment)*

TREATMENT SCHEDULE

LEFT SURFACE		RELIEF		TIME REACHED BOTTOM
DATE	TIME	TIME	DEPTH	
TIME ON BOTTOM		REACHED SURFACE		TREATMENT TABLE USED
MIN.		DATE	TIME	

DEPTH OF STOP		CHAMBER (*Stops filled in only when treatment table 3 or 4 is used or when other treatment tables are altered*)	
FEET	LBS	MINUTES AT STOP	BREATHING MEDIUM
165	73.4		
140	62.3		
120	53.4		
100	44.5		
80	35.6		
60	26.7		
50	22.3		
40	17.8		
30	13.4		
20	8.9		
10	4.5		
TO SURFACE			

RECURRENCE TREATMENT SCHEDULE

LEFT SURFACE		RELIEF		TIME REACHED BOTTOM
DATE	TIME	TIME	DEPTH	
TIME ON BOTTOM		REACHED SURFACE		TREATMENT TABLE USED
MIN.		DATE	TIME	

DEPTH OF STOP		CHAMBER (*Stops filled in only when treatment table 3 or 4 is used or when other treatment tables are altered*)	
FEET	LBS	MINUTES AT STOP	BREATHING MEDIUM
165	73.4		
140	62.3		
120	53.4		
100	44.5		
80	35.6		
60	26.7		
50	22.3		
40	17.8		
30	13.4		
20	8.9		
10	4.5		
TO SURFACE			

REMARKS: *(Include sequence of events preceding the accident and subsequent result of treatment, noting any unusual contributing factors - Use continuation sheet if needed)*

SIGNATURE OF MEDICAL DEPARTMENT REPRESENTATIVE

NAVMED 6420/1 (BACK)

FIGURE 1-39(b).—Report of decompression sickness and all diving accidents. Side 2 (form).

more than one log may be used. If this is done, give each a suitable designation.

Instructions

(4) Each diver entering the water should be recorded on a separate log sheet.

Use an ordinary No. 2 lead pencil to mark the appropriate categories. DO NOT USE A BALLPOINT PEN. Blacken completely the area between the dotted lines. Erase completely any marks you wish to change. Figures 1–37(*a*) and 1–37(*b*) are examples of a diving log sheet that has been properly marked. MAKE ONE AND ONLY ONE MARK PER HORIZONTAL ROW. If the information is unknown for a particular item, fill the area in with zeros.

Entries

(5) Most entries are self-explanatory. Amplifying remarks are listed below:

1. Reporting activity: Print the name and/or number of the reporting activity. This information will be coded by NAVXDIVINGU.

2. Date: Record the number of the month, day, and the last two digits of the year.

3. Name: Print the diver's last name, first name, and middle initial.

4. Service number: Record all seven digits of the enlisted service number. For officers, record a zero in the top column and then the six-digit file number. For enlisted service numbers the first digit should go in the top space on the log sheet, and the number recorded left to right, top to bottom.

5. Class diver: Specify the diver's present qualification. For more than one qualification, use the most recent.

6. Diver's age: Record age in years.

7. Diver's height: Record height in inches.

8. Diver's weight: Record weight in pounds.

9. Geographical location: Print the location where the dive actually was made.

10. Water depth: Record the sounded or lead-line depth in feet. The last digit of the depth figure should be placed in the bottom box of the depth area on the log sheet.

11. Wave height: Record the diving officer's best estimate of wave height in feet.

12. Current: Estimate the current in knots.

13. Water temperature: Record the measured water temperature in degrees Fahrenheit.

14. Type bottom: Specify the type bottom if known.

15. Visibility: Record the diver's best estimate of the water visibility at the depth at which he is working.

16. Purpose of dive: Specify the purpose of the dive.

17. Breathing apparatus: Specify the breathing apparatus used. If more than one apparatus was used, record the one used the longest.

18. Breathing medium: Specify the type of gas used as a breathing medium during the dive.

19. Record the nearest whole percent of helium used. For an air dive, record "00."

20. Record the nearest whole percent of oxygen used. For an air dive, record "0.21."

21. Record the nearest whole percent of nitrogen used. For an air dive, record "79."

22. Depth of dive: Record the greatest depth in feet attained during the dive. The rightmost digit of the depth figure should be placed in the lowest box in the depth area on the log sheet.

23. Bottom time: Record the elapsed time in minutes between leaving the surface in descent and leaving the bottom in ascent. The rightmost digit of the time figure should be placed in the lowest box in the time area on the log sheet.

24. Type of work: The diver's estimate of the level of effort required during the dive.

25. Tools used: Specify the one class of tools used most during the dive.

26. Number of dives made in previous 24 hours: Record the number of dives made in the 24 hours preceding the present dive.

27. Decompression schedule used: Specify the decompression category of the dive.

28. Schedule—depth/partial pressure: Record the decompression schedule depth or partial pressure used in figuring the dive decompression.

29. Schedule—time: Record the time used in figuring the dive decompression.

30. Location of decompression: Specify the conditions under which the decompression was carried out.

370-711 O—70——16

31. Whether the decompression schedule was accurately followed: Indicate (yes or no) whether the U.S. Navy Standard Decompression Tables were accurately followed.

32. Outcome of dive (medical): Specify the diver's condition. Minor diving accidents cover such things as squeezes, minor cuts, and swallowed air. Major diving accidents cover decompression sickness, embolism, etc. Elaborate on the back of the form any time a diving accident occurred. Major accidents also require the submission of a NAVMED 6420/1 (Rev. 3–67).

33. Total decompression time: Record the elapsed time in minutes between leaving the greatest depth attained and reaching the surface.

34. Outcome of dive (equipment): Indicate whether or not the equipment performed satisfactorily.

35. Decompression stops: Record the depth, time, and breathing media for all decompression stops.

36. Job description: Specify the purpose of the dive and whether or not the job was completed.

37. Additional remarks: This section may be used to amplify any information listed elsewhere on the form and to record any unusual features of the dive. Any categories of the reverse side that are marked as "Other" should be explained in this area.

Distribution

(6) Diving Log Books are distributed by:

Commanding Officer U.S. Naval Supply Center Norfolk, Va. 23512	Commanding Officer U.S. Naval Supply Center Oakland, Calif. 94625

One initial copy is distributed to each diving activity. Additional copies can be ordered from the above activities with the following stock numbers: Ring binder and instruction sheet 0105–643–2100; Dive Log sheets 0105–643–2000.

Disposition

(7) All diving activities shall submit their Diving Log sheets within 2 weeks after the end of each quarter. The log sheets will be sent, UNFOLDED AND UNMUTILATED, to:

Officer in Charge
U.S. Navy Experimental Diving Unit
Washington Navy Yard
Washington, D.C. 20390

Example

(8) Figure 1–37 is filled out as an example using the data given below:

1. Reporting activity	ASR 37.
2. Date	June 3, 1966.
3. Name	Frank S. Jones.
4. Service number	455 24 73.
5. Class diver	First class.
6. Diver's age	32 years.
7. Diver's height	5′11″—71″.
8. Diver's weight	175 pounds.
9. Geographical location	Key West Harbor Fla.
10. Water depth	30 feet.
11. Wave height	1 foot.
12. Current	½ knot.
13. Water temperature	Unknown.
14. Type bottom	Mud.
15. Visibility	20 feet.
16. Purpose of dive	Work.
17. Breathing apparatus	Lightweight.
18. Breathing medium	Air.
19. Percent helium	0.
20. Percent oxygen	21.
21. Percent nitrogen	79.
22. Depth of dive	20 feet.
23. Bottom time (minutes).	80 minutes.
24. Type work	Heavy.
25. Tools used	Handtools.
26. Number of dives made in previous 24 hours.	None.
27. Decompression schedule used.	No de-dive.
28. Schedule depth/partial pressure.	20 feet.
29. Schedule time	80 minutes.
30. Location of decompression.	Water.
31. Was the decompression schedule accurately followed?	Yes.
32. Total decompression time.	0.3 minute.
33. Outcome of dive (medical).	Diver OK.
34. Equipment (performance).	Satisfactory.
35. Decompression stops	20′–0′ in 0.3 min.
36. Job description	Screw change.
37. Additional remarks	None.
38. Signatures	Diving supervisor. Diving officer.

1.8.5 THE DIVER'S LOG BINDER

(1) A Diver's Log binder is issued to each graduate of the Naval School, Diving and Salvage. It is his personal record. The binder serves as a depository for his Diving Duty Summary forms.

(2) Training activities other than the Naval School, Diving and Salvage, should present suitable binders to divers of any designation qualified by them. Divers already qualified on promulgation of this article may use a file folder to hold their forms.

(3) The binder and its contents are available to the diving supervisor to assist him in the detailing of divers. Each diver is responsible for maintaining his own records and for presenting his binder on each new assignment to diving duty. Each command may establish its own system for assisting the divers in keeping their records current and for providing proper stowage.

(4) The Diver's Log is an official record and may be used for such purposes as determining the experience of divers and comparing the relative experience of several divers. Ultimately the log will be valuable when considering recommendation of a diver, first class, for advancement to master diver.

1.8.6 DIVING DUTY SUMMARY FORM

(1) Along with the log binder, each graduate of the Naval School, Diving and Salvage, is presented with two copies of a Diving Duty Summary Form. The initial entries recording qualification and the issuance of the log binder are completed and signed prior to presentation. The original is placed in the Diver's Log binder and the duplicate copy is placed in his service record.

(2) Training activities other than the Naval School, Diving and Salvage, should prepare similar forms for presentation to divers of any designation qualified by them. Commands having divers assigned should prepare forms for those divers already qualified on promulgation of this article. Those divers should estimate, to the best of their abilities from available records, prior diving experience and enter that information on the form for each former duty station. These entries may be certified by the diver's signature.

(3) It is then the diver's responsibility to insure that both copies of the form are maintained current with each permanent assignment to diving duty or with each assignment to requalification diving. Just prior to detachment, he must sum up in his copy all the diving he has performed. It must then be turned in to the ship's office for transcription in the duplicate copy. Both copies must then be signed by the commanding officer or his authorized representative before the diver is transferred. The signature on the diver's copy signifies that the command approves his record and that it has been transcribed to the official copy.

(4) This form, when properly filled out, represents a complete record of the diver's diving career. Each line entry represents a permanent assignment to diving duty. It includes all temporary additional duty assignments made within the permanent assignment period. One line may thus represent several years' service on board one command.

(5) On failure to retain diving qualification, or on final separation from active duty, the form must be completed and the duplicate forwarded to the Officer in Charge, Navy Experimental Diving Unit, Washington Navy Yard, Washing, D.C. 20390.

(6) Duplicate Diving Duty Summaries and Diver's Log binders may be requested from the Naval School, Diving and Salvage, when the original is verified lost or destroyed or when the individual reenlists after broken service.

(7) An individual who is retrained and redesignated at the Diving School after his previous qualification has lapsed is issued a new Diving Duty Summary. It must be the objective of all concerned to reduce to an absolute minimum the occasions requiring this retraining and redesignation.

1.8.7 REPORT OF DECOMPRESSION SICKNESS AND ALL DIVING ACCIDENTS

(1) The Report of Decompression Sickness and all Diving Accidents NAVMED 6420/1 (Rev. 3–67) round out the system of diving re-

ports. It provides data for analysis concerning the safety of decompression tables and the effectiveness of treatment procedures. It also supplies much valuable information concerning diving hazards of all kinds. Analysis of the reports plays an important role in the continual effort to improve diving practices and increase the safety of diving as a whole.

Accidents To Be Reported

(2) Reporting of the following types of accident is considered mandatory:

(*a*) Cases of decompression sickness requiring treatment; all cases of air embolism.

(*b*) All episodes of convulsion or serious impairment of consciousness during or after a dive, regardless of cause or outcome.

(*c*) Every accident that occurs during the course of a diving operation and results in death, serious injury, or more than brief incapacitation of the victim.

(*d*) Any serious mishap during the course of a dive (i.e., blowup, squeeze, fouling of more than brief duration, failure of scuba requiring free ascent from significant depth) even though the diver escapes actual injury.

(*e*) Any event or aftermath of a dive that requires medical treatment beyond simple first aid or routine measures.

(3) Because the basic purpose of NAVMED 6420/1 (Rev. 3–67) is to increase the overall safety of all aspects of diving operations, it is considered highly desirable to report *any* happening or observation that calls attention to a potential hazard or can otherwise contribute to safe practices. In this sense, for example, the report of a narrow escape from a serious accident under unusual circumstances would be of as much value as a report of a fatal accident of the same nature. It is also extremely desirable to report such observations as, for example, an unusual number of cases of a particular type of respiratory infection among a group of divers, or some peculiar set of symptoms appearing frequently when a certain type of equipment is used. It is only through such reporting that a new problem can be recognized early and steps taken to deal with it. (In some instances, for example, when a similar condition has been observed in a number of individuals, it may be more convenient to prepare a letter report than to utilize NAVMED 6420/1 (Rev. 3–67) itself; but the same basic instructions and distribution should be observed.)

Preparation

(4) The cognizant medical officer (normally the medical officer who treats the accident victim) is responsible for preparing the report. If no medical officer is attached to the activity or present at the time of the accident or treatment, the medical department representative (hospital corpsman) concerned must prepare and sign it. In this case, the report should also bear the signature of the cognizant medical officer, if any, with indication of his approval and/or comments. Where no medical officer or corpsman is present or directly concerned, preparation of NAVMED 6420/1 (Rev. 3–67) becomes the responsibility of the diving officer.

(5) The report form itself is largely self-explanatory. Any information not adequately covered by the spaces provided should be detailed under "Remarks." Enough information should be provided to permit anyone reading the report to obtain a clear picture of the accident, circumstances, treatment, and outcome.

(6) Prepare and submit NAVMED 6420/1 (Rev. 3–67) at once, unless the victim has residual symptoms and the final outcome remains in doubt. In such a case, prepare the body of the report immediately, but delay completion and submission (*not longer than 30 days*) to permit the actual or probable end result to be specified with reasonable accuracy. Where submission is delayed, insure that the report is not neglected. If the outcome remains uncertain as long as 30 days following the accident, submit the report with appropriate notations including the patient's condition at that time, medical opinion concerning probable course, and hospital to which patient was transferred (or other disposition). In such cases, supply a follow-up letter report at a later date whenever possible.

Distribution

(7) The Commanding Officer of the treating facility should send the original of NAVMED

6420/1 (Rev. 3–67) to the Bureau of Medicine and Surgery (Attn: Code 74), Navy Department, Washington, D.C. 20390. Send a legible copy to the Navy Experimental Diving Unit, Washington Navy Yard, Washington, D.C. 20390. Send a legible copy to Naval Submarine Medical Center, Naval Submarine Base, New London, Groton, Conn. 06342. (Retention of a copy in the files of the diving activity is recommended.)

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PART 2

SURFACE-SUPPLIED DIVING

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SECTION 2.1 STANDARD DIVING EQUIPMENT

2.1.1 CLASSIFICATION OF DIVING OUTFITS

General

(1) All the surface-supplied types of diving apparatus are supplied with air or some other suitable breathing medium through a hose from the surface. They are used mainly where the diver's work is confined to a rather small area and where stability rather than great mobility is important. Great depths and other special conditions may also require use of surface-supplied rigs. The fact that air-supply duration is not limited is a definite advantage of this type of equipment.

Deep-Sea Diving Outfit

(2) The deep-sea diving outfit, figures 2–1 and 2–2, consists essentially of a helmet and dress which provide watertightness, weighted belt and shoes used for overcoming positive buoyancy gained by the volume of the helmet and inflated dress, the hose and control valve whereby air is furnished and the quantity of air required is controlled, and the nonreturn valve which is used to prevent air escaping from the dress in the event of an accidental rupture of the airhose. The exhaust valve is spring loaded and adjustable. The balance between control valve and exhaust valve settings governs the pressure in the suit and thus controls the degree of inflation and the buoyancy.

(3) The deep-sea outfit has been used for a considerable number of years with remarkable success. In addition to all submarine rescue and salvage work undertaken in peacetime, practically all salvage work of any extent undertaken during World War II was accomplished using this equipment. The outfit is designed for extensive, rugged diving work and provides the diver with the maximum physical protection. It is intended that the deep-sea diving equipment be used for the following general types of work: submarine salvage—initial inspection, placing slings for pontoons, handling pontoons, attaching hose for blowing and venting; ship salvage—internal inspection, internal repairs, installations of large patches on ship hulls, construction of cofferdams; harbor work—where visibility is poor, working around stone walls, pilings, or where there may be sharp projections; general—diving to depths requiring decompression and working in heavy tideways. These are merely illustrations of the type of work undertaken using the deep-sea diving outfit. They are not intended to be all inclusive or specific. It should be noted that there are many diving operations involving the above conditions which are undertaken in shallow depths, but which require the use of the rugged deep-sea equipment, regardless of the depth at which the work is being done.

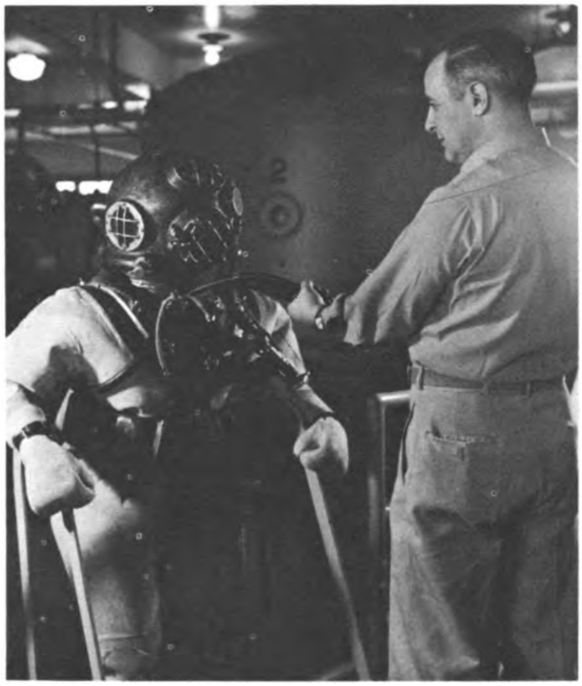

FIGURE 2–1.—Surface-supplied apparatus: deep-sea diving outfit.

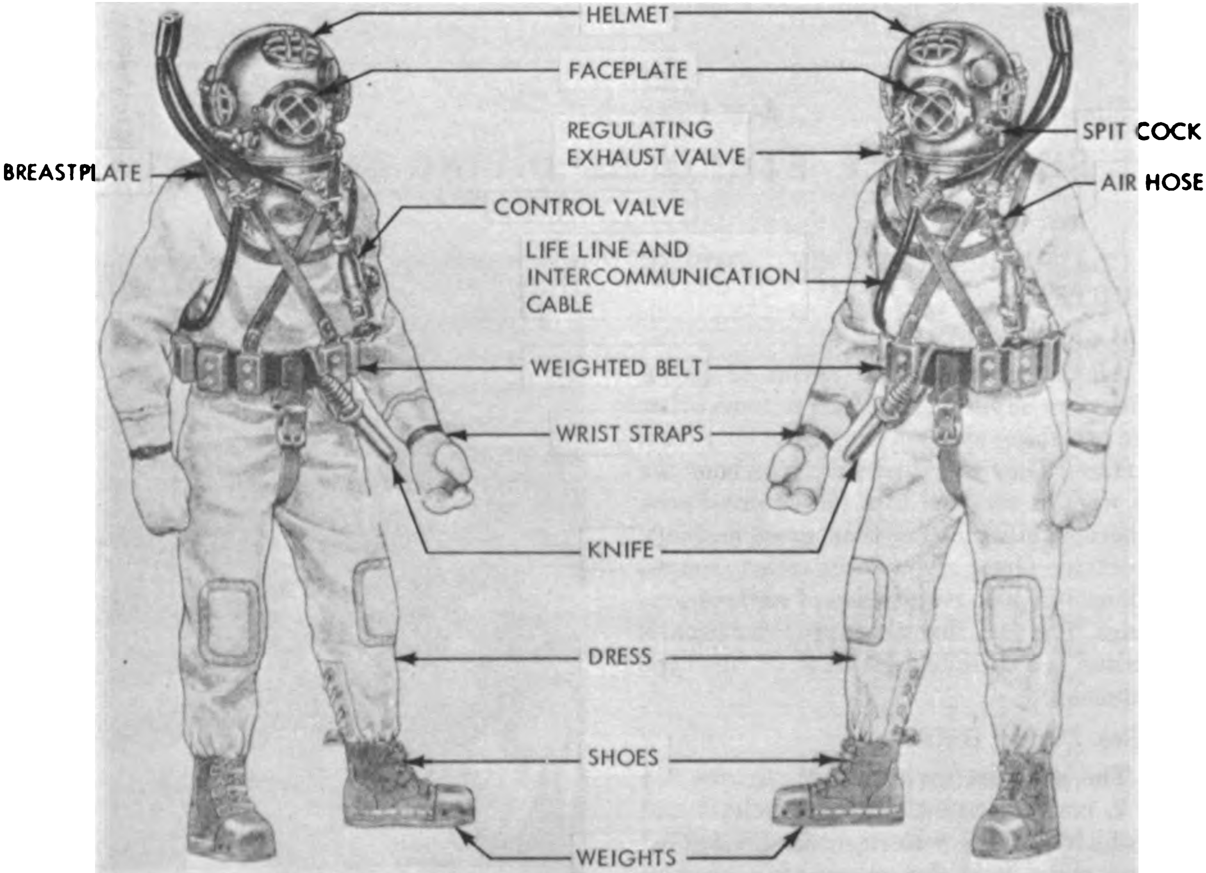

FIGURE 2-2.—Deep-sea diving outfit.

(4) There are two deep-sea diving outfits: No. 1 and No. 3. The No. 1 outfit is a heavy-duty outfit and contains all the material required for two divers plus additional spares to keep the outfit in repair for approximately 1 year. The outfit is issued only to vessels and shore activities that are called upon to undertake extensive diving operations—repair ships, tenders, salvage vessels, tugs, and diving boats.

(5) The No. 3 outfit is a special outfit issued only to submarine-rescue vessels. This outfit, in conjunction with the helium-oxygen equipment, is sufficient to undertake the diving necessary to effect the rescue of personnel from sunken submarines and the salvaging of a submarine.

Lightweight Diving Outfit

(6) The lightweight diving outfit consists essentially of a dress, mask, hose, belt, shoes, control and nonreturn valves. The outfit is designed with the intention of eliminating the bulkiness and weight of the deep-sea outfit. The essential part of the outfit (fig. 2-3) is a full face mask. This is supplied with air from the surface through a hose of the type generally used for oxygen. A nonreturn valve and an air-control valve are mounted on the right side of the mask, and an exhaust valve is provided on the left side. This mask can be used alone if desired, allowing the diver almost as much freedom, within limits, as with self-contained apparatus. A light, flexible dress is provided for use with the mask when desired. Because air enters and exhausts directly from the mask without entering the lightweight dress or wet suit, there is no excess of buoyancy with this rig. The weights provided can therefore be much lighter than with the deep-sea rig, and they are equipped with a quick-release fastening to permit them to be dropped rapidly in an emergency. A lifeline attached directly to the diver's body completes the lightweight outfit.

(7) The lightweight outfit can be used on a considerable number of different types of jobs where the working and diving conditions are not severe and access to the work is relatively unrestricted, such as inspection, searching, clearing lines, and external ship repairs. This type of work does not require the use of the heavy deep-sea equipment, but could not, in many instances, be accomplished with the shallow-water outfit because of water and temperature conditions. The lightweight outfit can be used in either of two ways, depending on the conditions: using the mask alone, or using the mask with the dress or a wet suit.

(8) The lightweight diving outfit contains sufficient equipment for two divers and spares to maintain the outfit in repair for a reasonable length of time. In addition to all diving vessels and stations, this outfit is furnished mainly to vessels—minecraft, patrol craft, auxiliaries, combatant vessels, and landing craft which have functions not primarily concerned with diving but which may find it necessary, at infrequent intervals, to do minor diving jobs of the type listed above. Only in extreme emergencies should diving be conducted below 60 feet or in any location that does not permit direct ascent to the surface. In no case will 130 feet be exceeded with the lightweight outfit.

FIGURE 2–3.—Lightweight diving outfit.

FIGURE 2–4.—Helium-oxygen equipment.

(9) Helium-oxygen equipment (fig. 2–4) is basically the same as the standard deep-sea outfit, with helmet modified to conserve the helium-oxygen mixture by recirculation through an absorbent. The exhaust system is provided with a special check-valve arrangement which makes it almost impossible for water to enter.

Component Parts

(10) The component parts of the deep-sea and lightweight diving outfits and the special equipment carried by submarine-rescue vessels for doing helium-oxygen diving are listed in table C–1 of appendix C.

2.1.2 DESCRIPTION AND CARE OF STANDARD DIVING EQUIPMENT

Equipment Used in Deep-Sea Diving

(1) In general, the items comprising the deep-sea diving outfit can be divided into three categories: first, those items used in dressing the divers; second, the items that are used by the diver to reach his task; and, third, the auxiliary

equipment to maintain the previously mentioned types of material.

Navy Standard Diving Helmet

(2) The Navy standard diving helmet assembly (figs. 2–5 and 2–6), designated as the Mk V, Mod I, consists of a spun-copper helmet with fittings and breastplate. The connection between the helmet and the breastplate is made by an interrupted-screw joint. Fitted into the recess of the threaded breastplate ring is a leather helmet gasket that serves a twofold purpose of making a watertight seal between the helmet and breastplate and controlling the distance that the helmet rotates. If the helmet gasket is of proper thickness, a moderate amount of force will line up the marks on the front of the helmet and breastplate within a reasonable distance and provide the necessary seal.

(3) There are a number of attachments to the helmet to provide the diver with necessary safety devices, sight, communication, and air supply and exhaust. To prevent the helmet from being accidentally disconnected from the breastplate, a safety lock (fig. 2–6) is attached to the back of the helmet. The ball lever that is secured to the helmet fits into the safety lock recess cut in the breastplate and prevents the helmet from moving more than the length of the recess opening. To prevent the ball lever from falling out of place, there is a safety latch secured to one end of the recess which fits over the ball lever and is secured to the other side of the recess by means of a brass cotter pin.

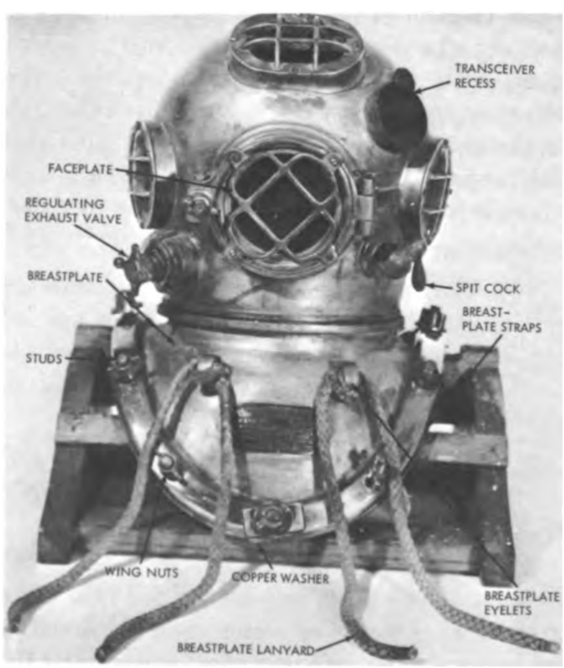

FIGURE 2–5.—Standard diving helmet assembly (front).

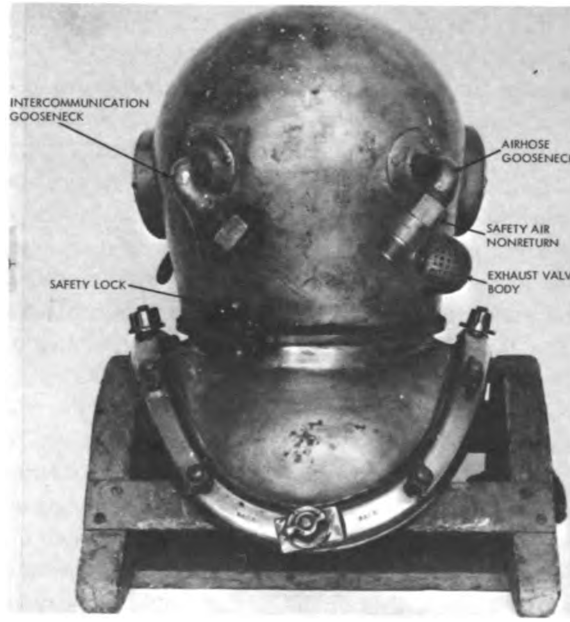

FIGURE 2–6.—Standard diving helmet assembly (rear).

(4) There are four ports on the helmet. The one directly in front of the diver's face is called the faceplate (fig. 2–5). The faceplate is hinged and is held in a closed position by means of a swing bolt and wingnut secured to the helmet, and which acts through two lugs on the faceplate. The wingnut of the bolt, when screwed down, fits into a countersunk recess in the two lugs of the faceplate, thereby preventing slippage or accidental displacement of the bolt from the faceplate. The joint made by the faceplate and the helmet is made watertight by a rubber gasket. The other three ports are located as follows: One on each side of the helmet, on the same level as the faceplate, to enable the diver to see laterally; and the third on the midline of the helmet above the faceplate to allow upward vision. All four ports are protected from breakage by brass guards. However, spare glasses are supplied in the event the glasses are accidentally broken.

(5) Two goosenecks are located on the back of the helmet (fig. 2–6). The one on the right side of the helmet is for attaching the safety air

nonreturn valve to which in turn is secured the diver's air hose, and the one on the left side is for attaching the amplifier and lifeline cable. The goosenecks are placed at an angle so that the air hose and lifeline fittings will not interfere with each other when secured to the goosenecks.

Safety Air Nonreturn Valve

(6) The safety air nonreturn valve is one of the most important safety devices supplied the diver. Its purpose is to prevent the diver from being injured by "squeeze" if his air hose bursts, or the air-supply system becomes so seriously damaged as to fail to maintain an air pressure sufficient to counteract the external water pressure. Under either of these conditions, the air pressure in the hose would fall suddenly. If the compressed air in the helmet and dress should escape through the air hose, the pressure within the helmet and dress would become less than the external water pressure. Because the helmet is rigid and the dress is flexible, the greater external pressure would squeeze the diver's body into his helmet in the same manner that a cork is forced into an empty bottle when lowered into deep water.

(7) It is essential that the safety air nonreturn valve function properly at all times. It must be carefully tested before a diver is permitted to descend. It should be examined frequently, disassembled, and cleaned. The leather valve-seat washer of the spring and stem type valve and the cartridge and O-ring of the cartridge-type valve should be inspected for wear and tear, cleaned, and given a coating of neat's-foot oil. The valve spring, valve stem, or valve cartridge, whichever one applies, should also be given a light coat of neat's-foot oil. To test the valve after assembly, screw it in the reverse manner to the end of a length of air hose, attach the hose to the air supply, and apply pressure.

(8) There are two types of diver's air nonreturn valve: the spring and stem type and the cartridge O-ring type shown in figures 2–7(*a*)

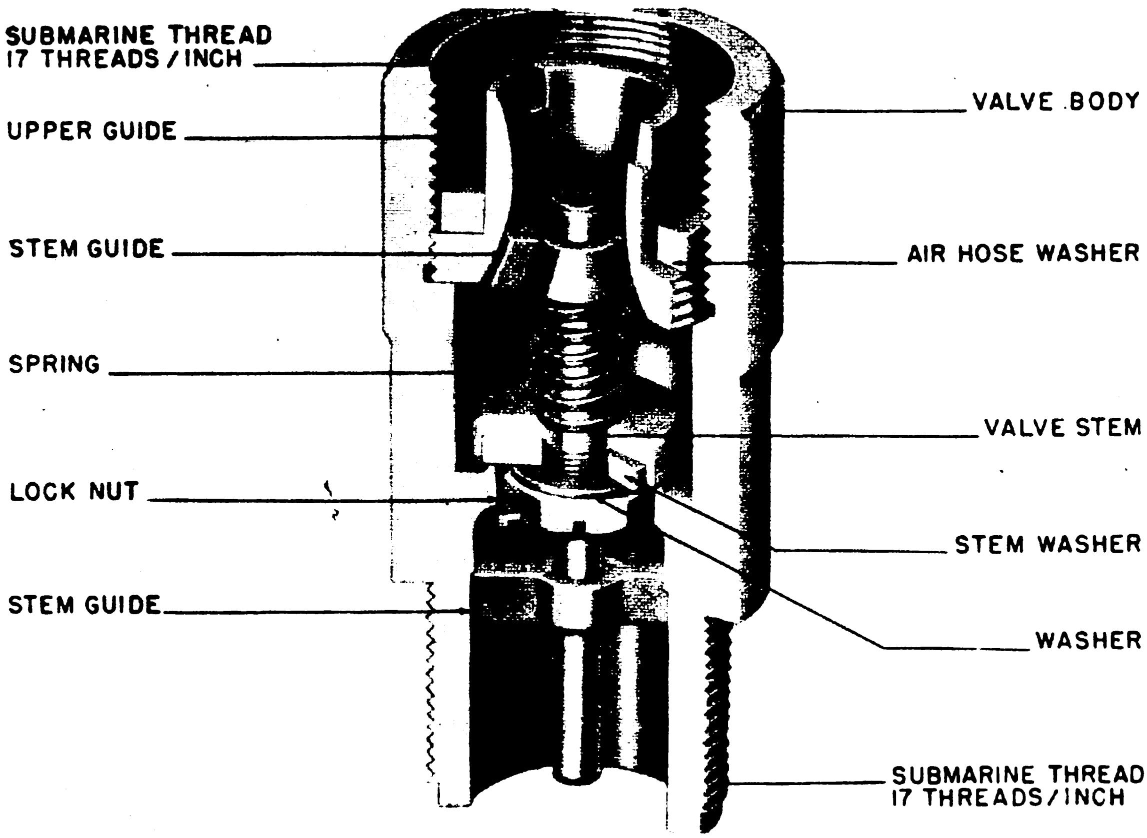

FIGURE 2–7(*a*).—Safety air nonreturn valve, spring and stem type.

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General

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(2) The deep-sea diving outfit, figures 2–1 and 2–2, consists essentially of a helmet and dress which provide watertightness, weighted belt and shoes used for overcoming positive buoyancy gained by the volume of the helmet and inflated dress, the hose and control valve whereby air is furnished and the quantity of air required is controlled, and the nonreturn valve which is used to prevent air escaping from the dress in the event of an accidental rupture of the airhose. The exhaust valve is spring loaded and adjustable. The balance between control valve and exhaust valve settings governs the pressure in the suit and thus controls the degree of inflation and the buoyancy.

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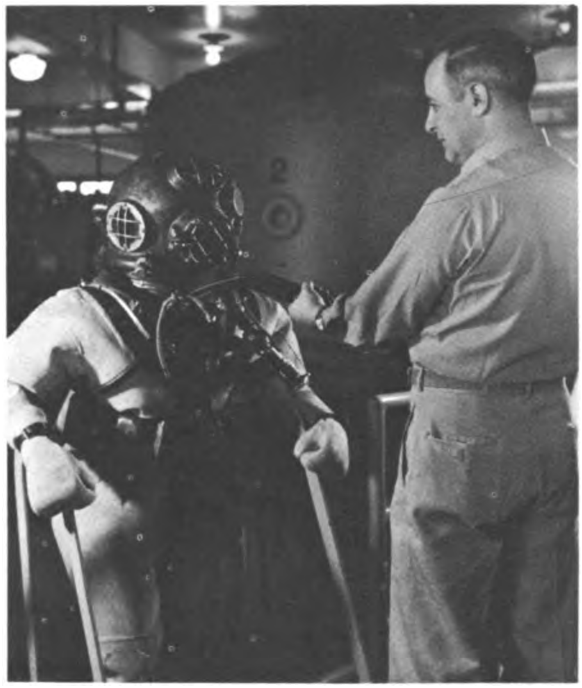

FIGURE 2–1.—Surface-supplied apparatus: deep-sea diving outfit.

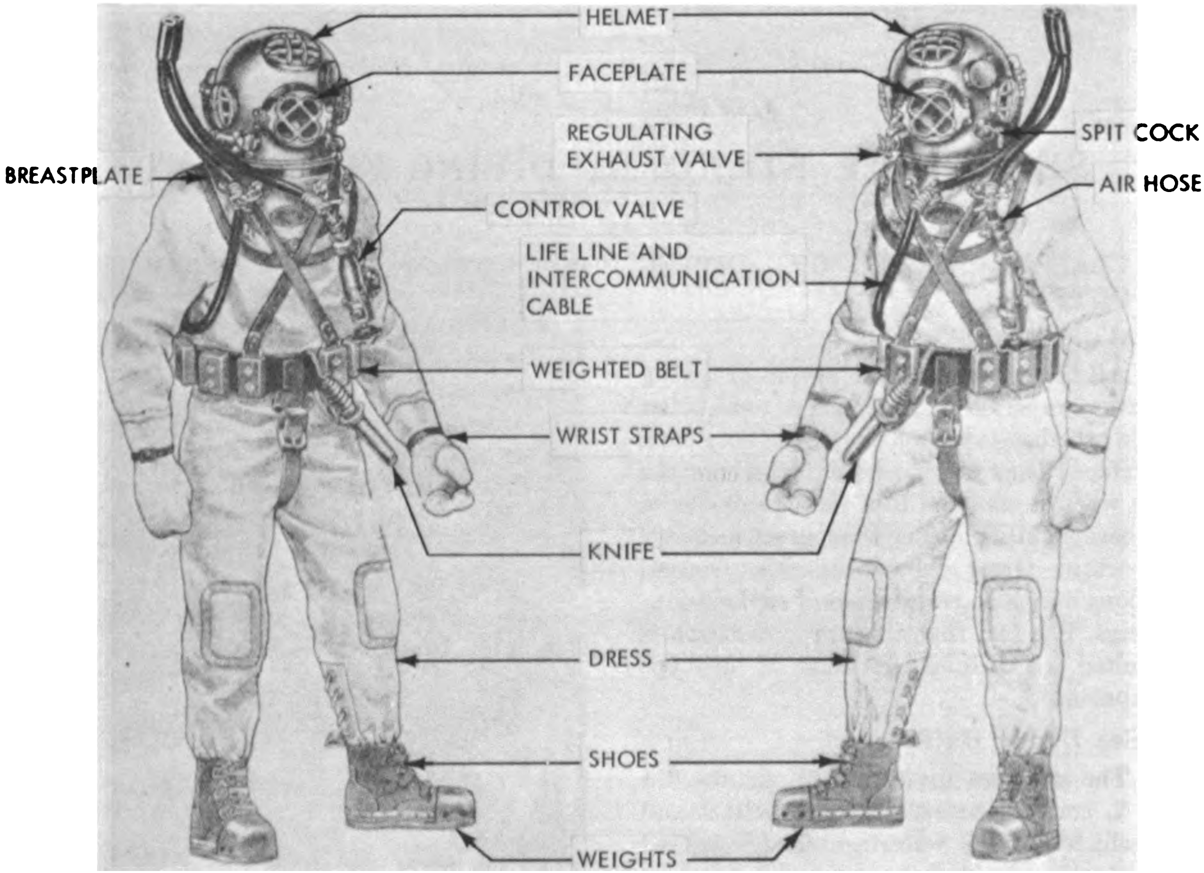

FIGURE 2-2.—Deep-sea diving outfit.

(4) There are two deep-sea diving outfits: No. 1 and No. 3. The No. 1 outfit is a heavy-duty outfit and contains all the material required for two divers plus additional spares to keep the outfit in repair for approximately 1 year. The outfit is issued only to vessels and shore activities that are called upon to undertake extensive diving operations—repair ships, tenders, salvage vessels, tugs, and diving boats.

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Lightweight Diving Outfit

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(7) The lightweight outfit can be used on a considerable number of different types of jobs where the working and diving conditions are not severe and access to the work is relatively unrestricted, such as inspection, searching, clearing lines, and external ship repairs. This type of work does not require the use of the heavy deep-sea equipment, but could not, in many instances, be accomplished with the shallow-water outfit because of water and temperature conditions. The lightweight outfit can be used in either of two ways, depending on the conditions: using the mask alone, or using the mask with the dress or a wet suit.

(8) The lightweight diving outfit contains sufficient equipment for two divers and spares to maintain the outfit in repair for a reasonable length of time. In addition to all diving vessels and stations, this outfit is furnished mainly to vessels—minecraft, patrol craft, auxiliaries, combatant vessels, and landing craft which have functions not primarily concerned with diving but which may find it necessary, at infrequent intervals, to do minor diving jobs of the type listed above. Only in extreme emergencies should diving be conducted below 60 feet or in any location that does not permit direct ascent to the surface. In no case will 130 feet be exceeded with the lightweight outfit.

FIGURE 2-3.—Lightweight diving outfit.

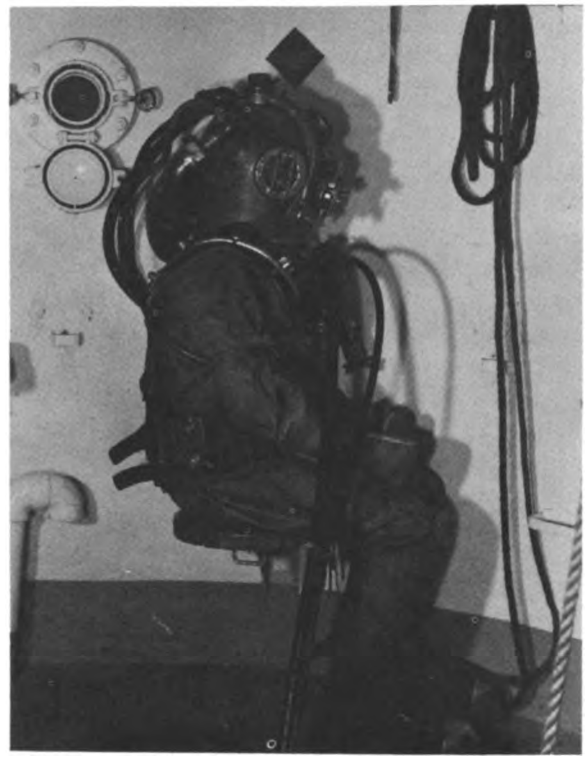

FIGURE 2-4.—Helium-oxygen equipment.

(9) Helium-oxygen equipment (fig. 2-4) is basically the same as the standard deep-sea outfit, with helmet modified to conserve the helium-oxygen mixture by recirculation through an absorbent. The exhaust system is provided with a special check-valve arrangement which makes it almost impossible for water to enter.

Component Parts

(10) The component parts of the deep-sea and lightweight diving outfits and the special equipment carried by submarine-rescue vessels for doing helium-oxygen diving are listed in table C-1 of appendix C.

2.1.2 DESCRIPTION AND CARE OF STANDARD DIVING EQUIPMENT

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(2) The Navy standard diving helmet assembly (figs. 2-5 and 2-6), designated as the Mk V, Mod I, consists of a spun-copper helmet with fittings and breastplate. The connection between the helmet and the breastplate is made by an interrupted-screw joint. Fitted into the recess of the threaded breastplate ring is a leather helmet gasket that serves a twofold purpose of making a watertight seal between the helmet and breastplate and controlling the distance that the helmet rotates. If the helmet gasket is of proper thickness, a moderate amount of force will line up the marks on the front of the helmet and breastplate within a reasonable distance and provide the necessary seal.

(3) There are a number of attachments to the helmet to provide the diver with necessary safety devices, sight, communication, and air supply and exhaust. To prevent the helmet from being accidentally disconnected from the breastplate, a safety lock (fig. 2-6) is attached to the back of the helmet. The ball lever that is secured to the helmet fits into the safety lock recess cut in the breastplate and prevents the helmet from moving more than the length of the recess opening. To prevent the ball lever from falling out of place, there is a safety latch secured to one end of the recess which fits over the ball lever and is secured to the other side of the recess by means of a brass cotter pin.

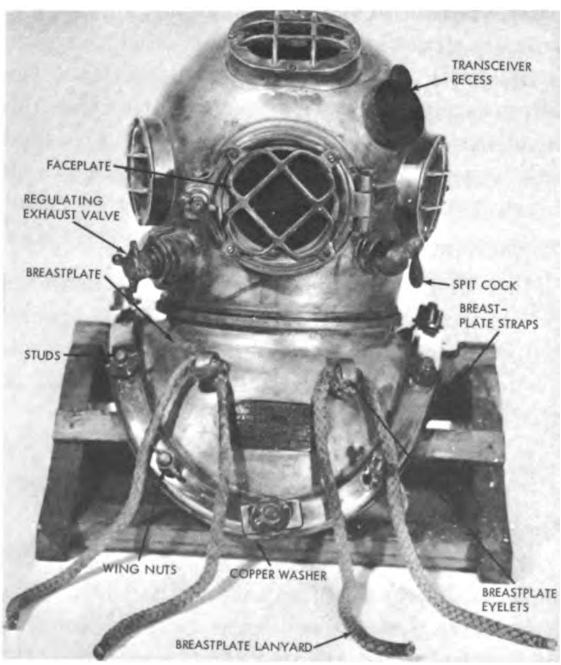

FIGURE 2-5.—Standard diving helmet assembly (front).

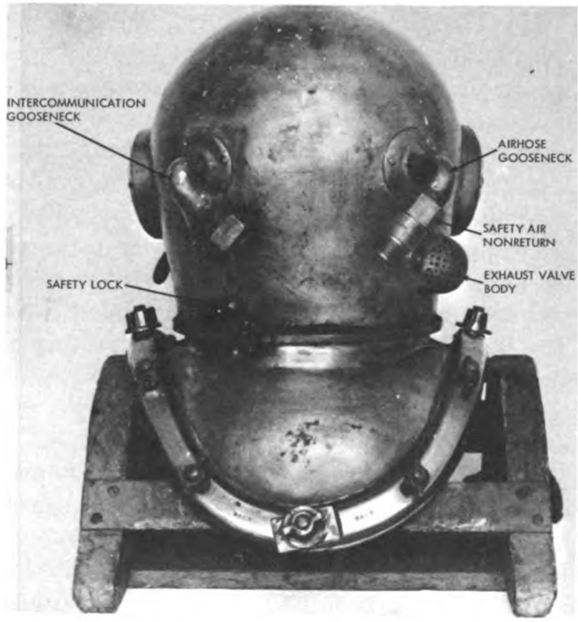

FIGURE 2-6.—Standard diving helmet assembly (rear).

(4) There are four ports on the helmet. The one directly in front of the diver's face is called the faceplate (fig. 2-5). The faceplate is hinged and is held in a closed position by means of a swing bolt and wingnut secured to the helmet, and which acts through two lugs on the faceplate. The wingnut of the bolt, when screwed down, fits into a countersunk recess in the two lugs of the faceplate, thereby preventing slippage or accidental displacement of the bolt from the faceplate. The joint made by the faceplate and the helmet is made watertight by a rubber gasket. The other three ports are located as follows: One on each side of the helmet, on the same level as the faceplate, to enable the diver to see laterally; and the third on the midline of the helmet above the faceplate to allow upward vision. All four ports are protected from breakage by brass guards. However, spare glasses are supplied in the event the glasses are accidentally broken.

(5) Two goosenecks are located on the back of the helmet (fig. 2-6). The one on the right side of the helmet is for attaching the safety air

nonreturn valve to which in turn is secured the diver's air hose, and the one on the left side is for attaching the amplifier and lifeline cable. The goosenecks are placed at an angle so that the air hose and lifeline fittings will not interfere with each other when secured to the goosenecks.

Safety Air Nonreturn Valve

(6) The safety air nonreturn valve is one of the most important safety devices supplied the diver. Its purpose is to prevent the diver from being injured by "squeeze" if his air hose bursts, or the air-supply system becomes so seriously damaged as to fail to maintain an air pressure sufficient to counteract the external water pressure. Under either of these conditions, the air pressure in the hose would fall suddenly. If the compressed air in the helmet and dress should escape through the air hose, the pressure within the helmet and dress would become less than the external water pressure. Because the helmet is rigid and the dress is flexible, the greater external pressure would squeeze the diver's body into his helmet in the same manner that a cork is forced into an empty bottle when lowered into deep water.

(7) It is essential that the safety air nonreturn valve function properly at all times. It must be carefully tested before a diver is permitted to descend. It should be examined frequently, disassembled, and cleaned. The leather valve-seat washer of the spring and stem type valve and the cartridge and O-ring of the cartridge-type valve should be inspected for wear and tear, cleaned, and given a coating of neat's-foot oil. The valve spring, valve stem, or valve cartridge, whichever one applies, should also be given a light coat of neat's-foot oil. To test the valve after assembly, screw it in the reverse manner to the end of a length of air hose, attach the hose to the air supply, and apply pressure.

(8) There are two types of diver's air nonreturn valve: the spring and stem type and the cartridge O-ring type shown in figures 2–7(*a*)

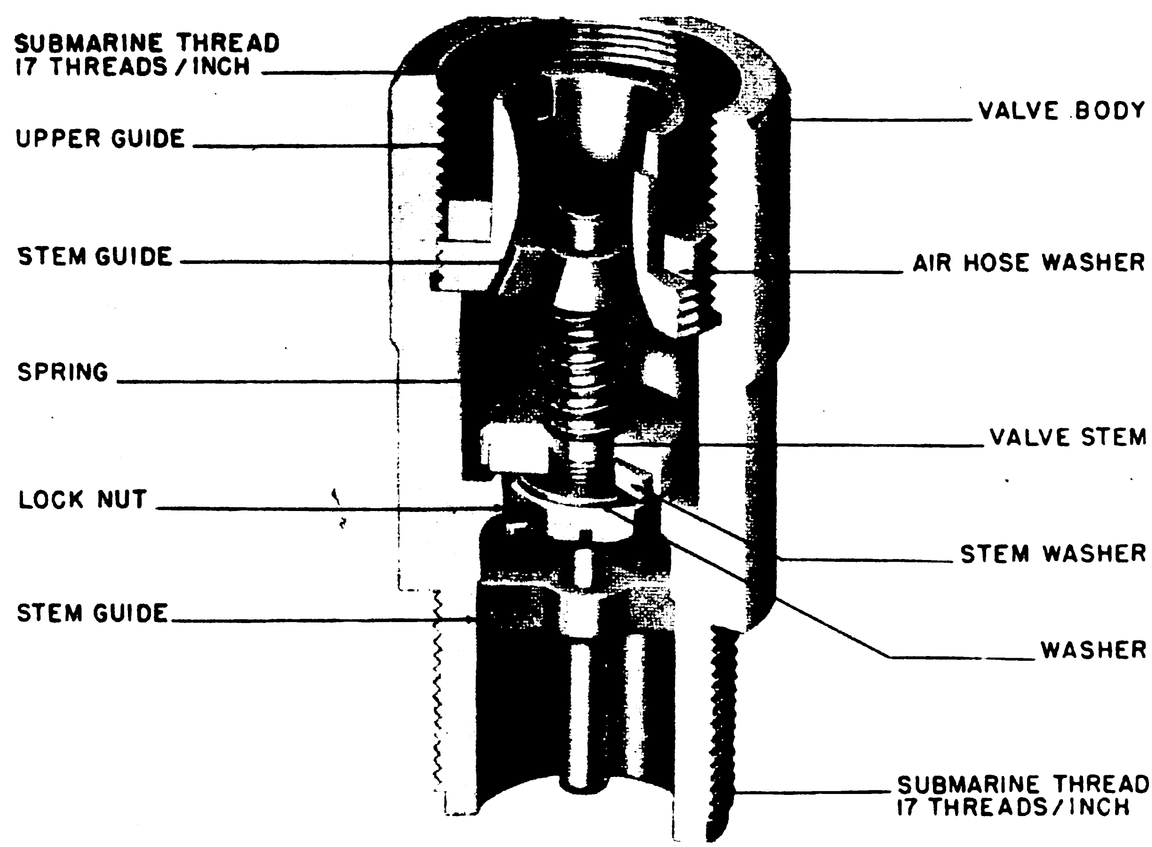

FIGURE 2–7(*a*).—Safety air nonreturn valve, spring and stem type.

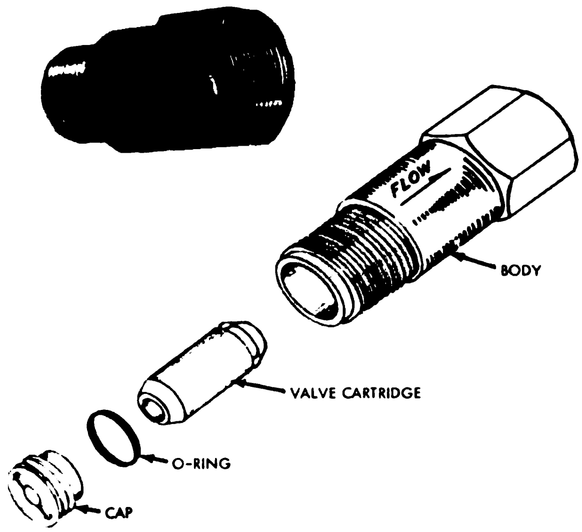

FIGURE 2–7(*b*).—Safety air nonreturn valves, cartridge and O-ring type.

and 2–7(*b*). Careful attention should be given to testing the valve for positive closure at low-pressure differentials in the range one-half to three-fourths psi. The lower pressures are more likely to be vital because high pressures will tend to seat the valve and assist in making an airtight seal. In actual diving, the internal pressure is not likely to exceed the external pressure by more than 1 psi. The valve should be immersed in water to see if any bubbles of air come from it. If none appear, the valve is tight; if not, a new leather washer, spring, or both, for the spring and stem type valve and a new cartridge insert and O-ring for the cartridge type should be installed and the test repeated. The cartridge valve body and cartridge insert are both marked with arrows that indicate the direction of airflow to assist in installation. When screwed in place on the air connection of the helmet, the valve should be tried to see that it works freely and seats properly on release of pressure. The inside diameter of the gasket between the valve and gooseneck should be checked because it is possible, by setting up tight on the valve, to spread the gasket so that its edge is forced into the air passage, thereby greatly restricting the flow of air to the diver. If these precautions are carefully observed, the safety valve is absolutely dependable in an emergency; if neglected, the valve may fail at a critical time with disastrous results.

Exhaust Valve

(9) The air-regulating exhaust valve (fig. 2–8) is located below the port along the right side of the helmet, together with the escape channel, so that the point of exhaust is toward the rear of the helmet. The position of the exhaust prevents air bubbles from passing in front of the faceplate and obstructing the diver's view. The purpose of the exhaust valve is to maintain, automatically, an air pressure in the diving helmet slightly in excess of the outside water pressure and to provide a means whereby the diver can regulate the inflation of his dress and consequently his buoyancy.

(10) As the diver enters the water, the diving dress is subjected to an external pressure that tends to force the air in the dress up into the helmet and then out of the exhaust valve. If the escape of this air is not retarded, or if the air supply is inadequate, the dress will collapse. With a normal air supply and no means to regulate its flow from the helmet, too great an inflation of the dress will result and be followed by an excess of positive buoyancy.

(11) If a diver finds it necessary to provide increased buoyancy, it is accomplished by closing the exhaust valve the necessary amount, thus allowing the dress to inflate. If there is danger of overinflation, buoyancy may be decreased by opening the valve, which causes the dress to deflate. The throw of the stem, through the medium of the chin button, is provided as a means of rapid release of all excess air.

(12) The exhaust valve should be inspected prior to each period of diving after prolonged inactivity and weekly, while diving, to insure that it is clean and lightly oiled, that the exhaust tube is clean, and that the valve seat is tight. The primary spring should be activated when the pressure on the seat exceeds the outside pressure by one-half psi and the secondary spring should be activated when the internal pressure exceeds external pressure by 2 psi. A failure of the exhaust valve might result in "blowing up" of the diver. A detailed description of the valve is in appendix C.

Other Attachments to Helmet

(13) Directly opposite the regulating escape valve is a supplementary exhaust valve called the "spit cock" (fig. 2–5). The valve is operated

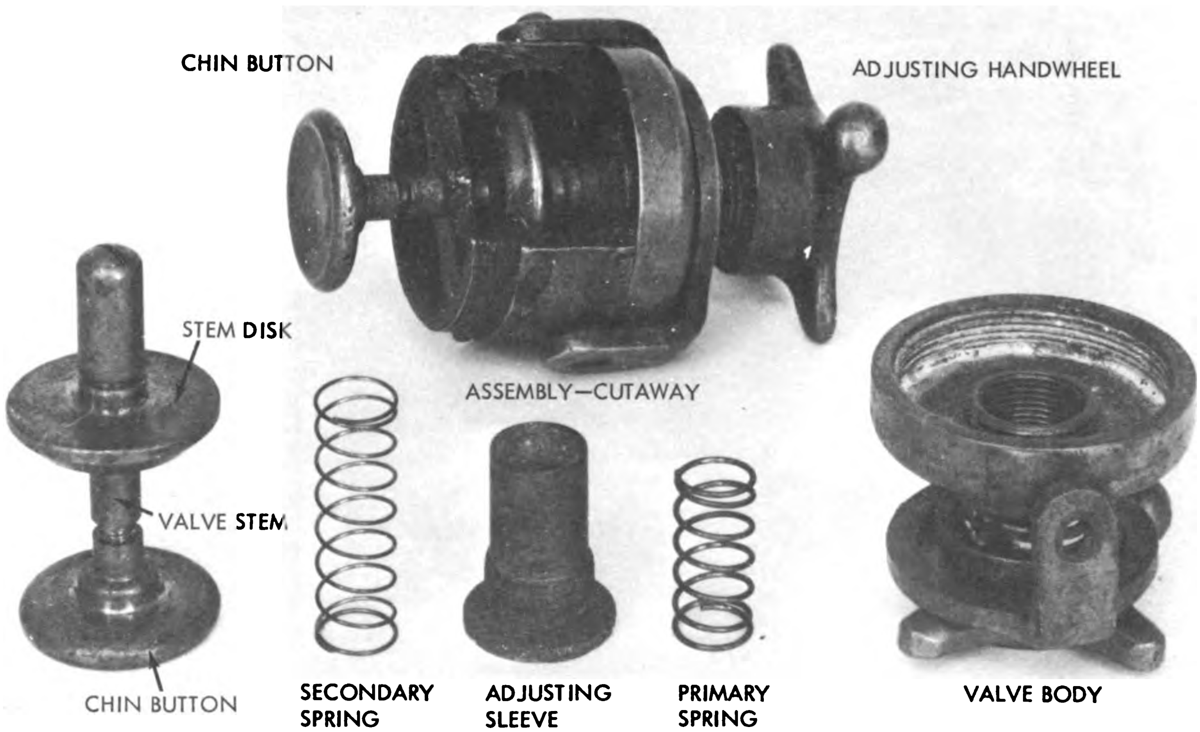

FIGURE 2-8.—Air-regulating exhaust valve.

by means of a lever-type handle and, when used in conjunction with the regulating exhaust valve, permits a fine adjustment of the diver's buoyancy.

(14) On the inside of the helmet, an air channel is sweated to the top of the helmet, with branches leading to, and terminating just over, the top and side ports to deflect incoming air away from the diver's head and over the port glasses.

(15) The necessary screws, bolts, and clips are located inside the helmet for securing the diver's reproducer and to hold the electrical wires in place.

Breastplate

(16) The breastplate (fig. 2-9) is shaped so that it fits comfortably over the shoulders, chest, and back. The neck portion of the breastplate has a threaded ring that screws into the ring on the helmet. A heavy shoulder collar is soldered around the edge of the breastplate through which are secured 12 equally spaced studs that fit into the holes molded into the diving dress gasket. A watertight seal is made by placing the dress gasket over the studs and then placing four removable breastplate straps over the dress gasket. Copper washers are placed under the removable breastplate straps at the junction to assist in making a seal at these points. The breastplate straps are then clamped in place by wingnuts, with flanged wingnuts used at the junction of the breastplate straps. On the left side of the breastplate is one long stud, called the "bastard stud," used to secure the link of the air-control valve. The two pad eyes on the front of the breastplate are used for securing the lifeline and air hose.

Welding Faceplate

(17) The welding faceplate (fig. 2-10) consists of a metal frame with an open section for inserting the welding lens, and is attached to the helmet by means of the helmet faceplate hinge bolt. The diving helmet has spring clips for holding the welding faceplate in an open or closed position. A more detailed figure of the welding faceplate is in appendix C.

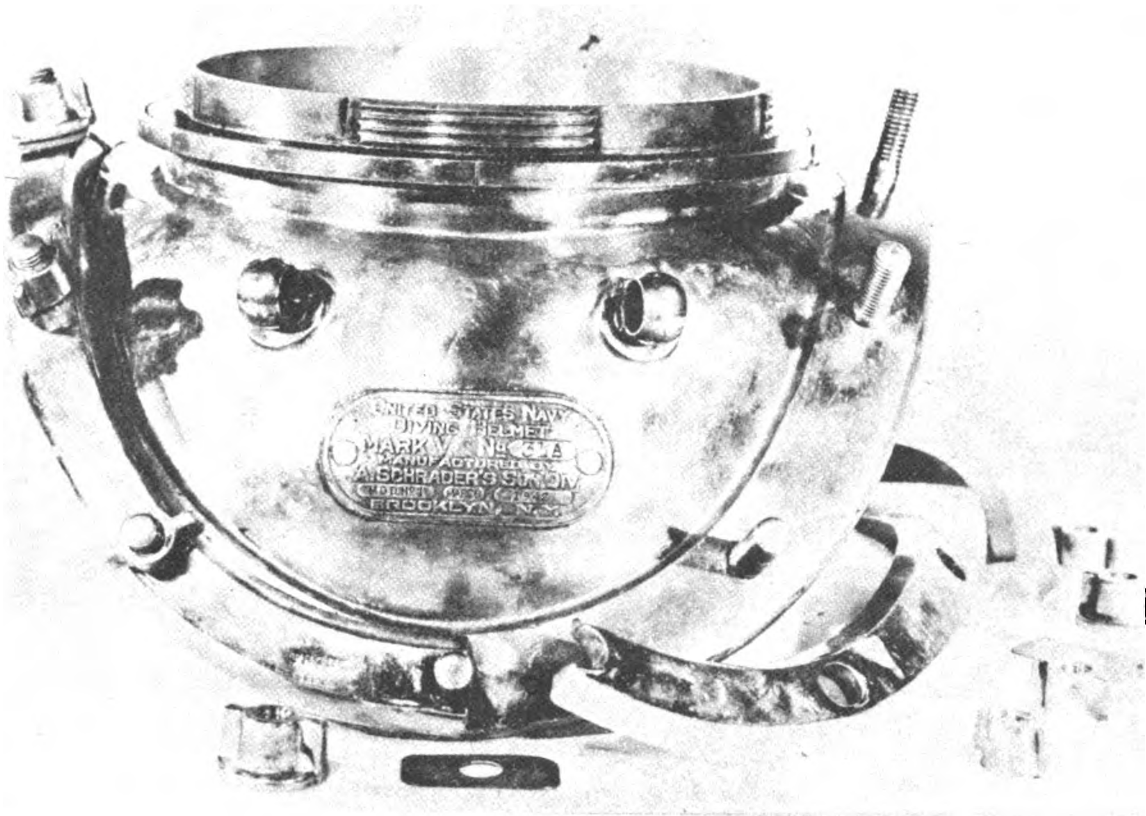

Figure 2-9.—Breastplate.

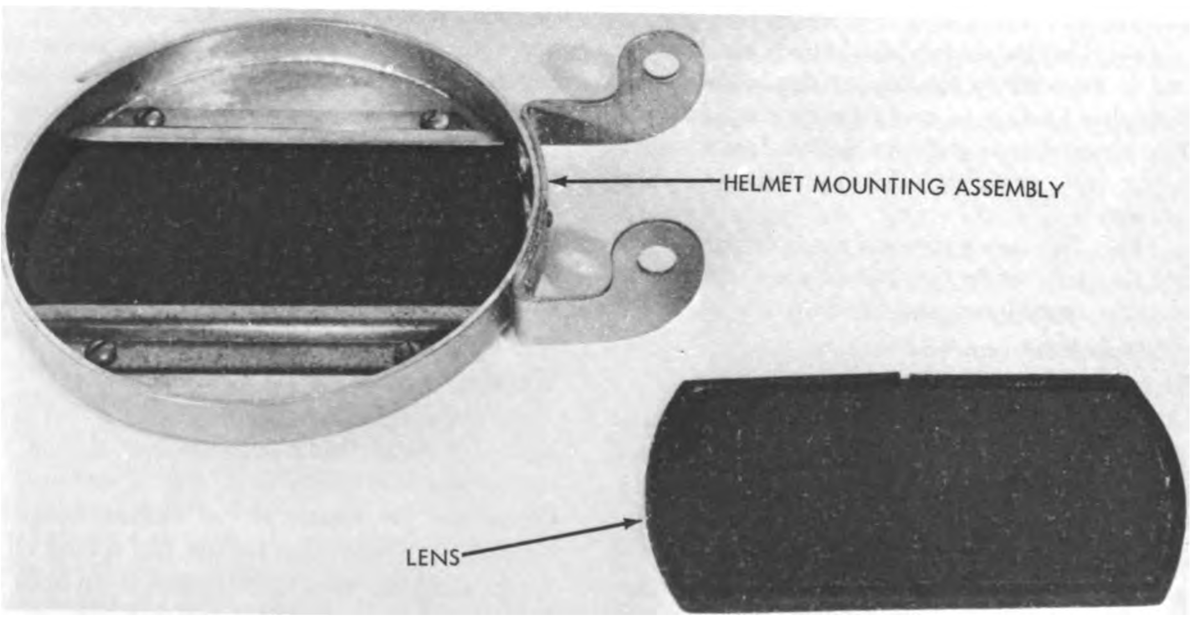

Figure 2-10.—Welding faceplate.

Welding Lenses

(18) The welding lenses are furnished in three shades: Nos. 4, 6, and 8. The shade number signifies the visible rays transmitted through the lens—the amount of light transmitted through the lens decreases as the shade number increases. The lens that is to be used for an underwater welding job will depend on the turbid conditions of the water. In muddy water, the No. 4 lens should be used; as the water becomes clearer, the No. 6 or No. 8 lenses should be used.

Maintenance of Helmet

(19) After use the helmet should be wiped inside and out with a dry cloth to remove any accumulation of moisture. When the helmet is used frequently, it is recommended that a permanent rack, with an electric light bulb that fits inside the helmet, be made to hold the helmet. This will assist in keeping the helmet dry and keep the diver's reproducer in good working condition. If the helmet is not to be used for some time, it should be dried thoroughly, preferably by using the light bulb method, and then stowed in the helmet chest.

(20) Inspect the gooseneck washers and see that the telephone connections are made watertight. Any time the airhose or lifeline and telephone cable are not attached to the helmet, the blank caps should be screwed on the goosenecks to protect the threads. Examine the faceplate hinge, hinge pin, rubber gasket, and wingnut for possible defects. Insure that the helmet and screw ring thread are free of burs and other defects.

(21) Inspect the breastplate studs for defects and tightness and insure that the nuts turn freely on them. Special care should be taken so that the breastplate straps do not become bent or injured; this will save an endless amount of trouble in making a tight joint at the junction of the diving dress and breastplate. The straps should be put in place and the wingnuts lightly screwed onto the studs to prevent damage to the threads.

(22) Check the leather helmet gasket to insure that it seats evenly all around, and see that it is treated with neat's-foot oil occasionally. If, as a result of wear, the helmet will turn so far on its breastplate that the safety lock at the back is past its recess and the faceplate is not directly in front of the diver's face, one or more paper washers should be cut and inserted under the helmet gasket on the breastplate, or a new gasket should be fitted. Insure that all metal parts are free from verdigris and corrosion.

Diving Dress

(23) The diving dress (fig. 2–11) is so constructed that it encloses the entire body with the exception of the head and hands, and when used with the diving helmet and gloves, it provides the diver with a complete watertight covering. The dress is made of vulcanized sheet rubber between layers of cotton twill. A heavy rubber gasket is fitted around the neck of the dress through which reinforced holes are molded to fit the studs of the helmet breastplate. A fitted dress fabric called the bib is around the neck on

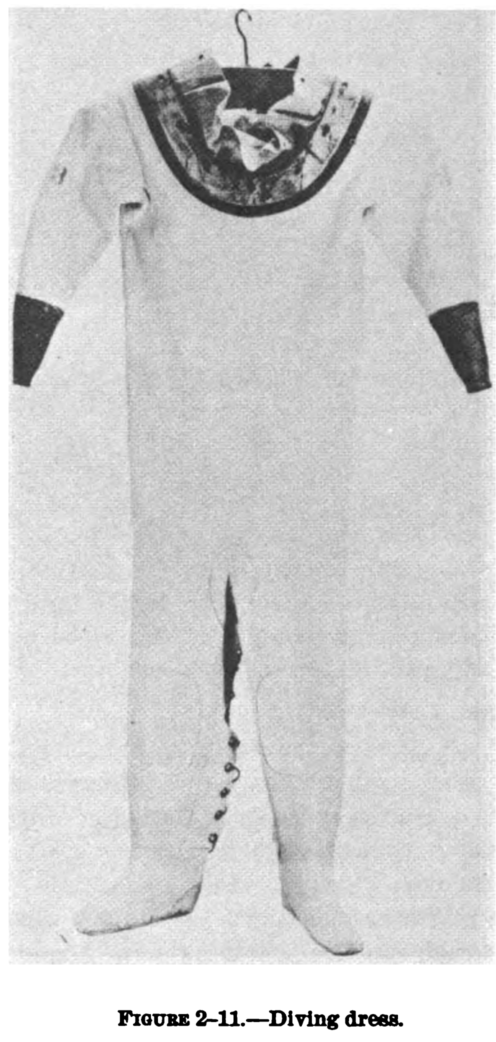

FIGURE 2–11.—Diving dress.

the inside of the dress. The bib is in the form of a cylinder that fits loosely and comes up well around the diver's neck to trap any water that may enter the helmet through the valves.

(24) To prevent an accumulation of air in the lower portion of the dress, flaps for lacing are provided over the rear portion of both legs of the dress. The lacing of the lower part of the dress lessens the danger of accidental blowup and risks incident to capsizing. A diver should not be put into the water unless the flaps are snugly laced.

(25) Navy diving dresses are designed especially to fit the Mk V, Mod I, helmet and are furnished in three sizes: No. 1, small; No. 2, medium; and No. 3, large. The No. 1 dress is designed to fit divers 5 feet 7 inches to 5 feet 9 inches tall; the No. 2 dress for divers 5 feet 9 inches to 5 feet 11 inches tall; the No. 3 dress is for divers 5 feet 11 inches to 6 feet 2 inches tall.

(26) To lengthen the life of the diving dress, chafing patches have been cemented to the dress at the points most likely to be subjected to the greatest amount of wear—elbows, knees, crotch, and toe. Repair cloth of rubberized twill is furnished to repair the dress. To patch a diving dress, see the instructions in appendix C.

(27) After using the diving dress, it should be washed inside and out with clean fresh water, turned inside out and hung in the shade to dry, and then turned right side out and repaired if necessary. An easy and efficient way to dry the dress is to fasten together two 8-foot wooden strips and place them vertically inside the dress. Pass another strip of wood through the arms so they are extended. The dress must be thoroughly dry inside and out before storing or it will mildew and rot. The dress should not be folded during storage; it should be hung on a hanger or left on the wooden strips.

Rubber Cuffs

(28) To enclose the hands or make a watertight seal at the wrist, either divers-tenders gloves or rubber cuffs can be used, according to the water temperature and type of work to be undertaken.

(29) Rubber cuffs (fig. 2–12) are used when it is desirable and feasible to have the hands exposed. The cuff is designed so that one end has the same diameter as the lower part of the dress sleeve, and the other end is about the size of the average diver's wrist. If a diver has large wrists and the cuff interferes with circulation of blood to the hands, a small amount of material can be cut from the small ends of the cuffs so that a comfortable fit is obtained. If the wrist end of the cuff is too large, a piece of elastic tubing is used to make a watertight seal between the diver's wrists and the cuff. The elastic tubing is made of pure rubber with an inside diameter of 1½ inches and is supplied in 3-foot lengths. The tubing normally is 1 to 2 inches long; however, the length will depend on the individual diver's preference. See appendix C for the method of attaching the cuff to the dress.

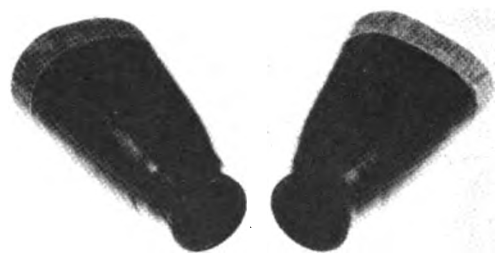

FIGURE 2–12.—Rubber cuffs.

Divers-Tenders Gloves

(30) The gloves (fig. 2–13(*a*)) used by both divers and divers' tenders are generally referred to as divers-tenders gloves. The gloves are intended for use in cold water or where the type of work to be done is likely to injure the hands.

(31) The divers-tenders glove is a three-fingered glove molded in a semiclosed position so there will be no strain on the diver's hand when holding a tool. The palm of the glove is shaped so that it still conforms to the shape of the div-

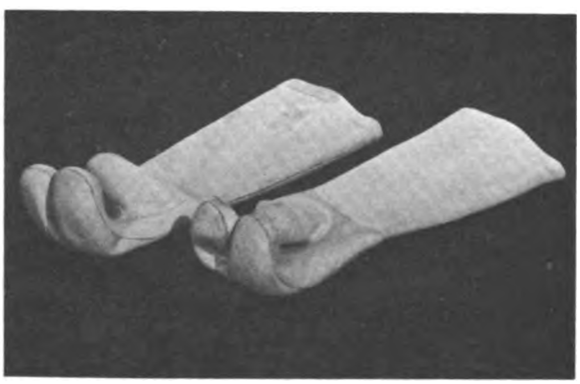

FIGURE 2–13(*a*).—Divers-tenders gloves.

er's palm when the hand is closed. When the gloves are attached, the arms of the dress are not adjustable and some divers have difficulty keeping the hands all the way in the gloves. To overcome this condition, wrist straps (fig. 2–13(*b*))

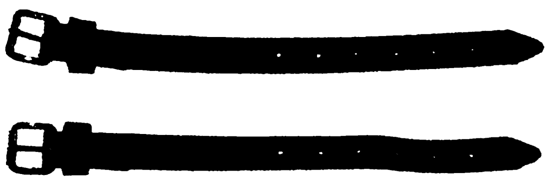

FIGURE 2–13(*b*).—Wrist straps.

made of chrome-tanned leather are furnished. The method for attaching the divers-tenders glove to the dress and methods to repair the glove are shown in appendix C.

Helmet Cushion

(32) The helmet cushion (fig. 2–14) is worn around the neck under the dress to prevent the helmet and weighted belt from bearing directly

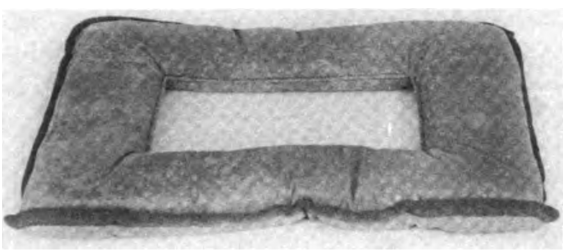

FIGURE 2–14.—Helmet cushion.

on the diver's shoulders when he is out of the water. The cushion is made of canvas padded with hair felt. The cushion should be thoroughly dry before storing.

Overalls

(33) The trousers (overalls) (fig. 2–15) are made of light canvas and are used to protect the diving dress against wear and chafe. The overalls are fastened to the diver by means of a cord which is run through the top of the trousers. After use, the trousers should be washed with clean water and allowed to dry thoroughly before being stored.

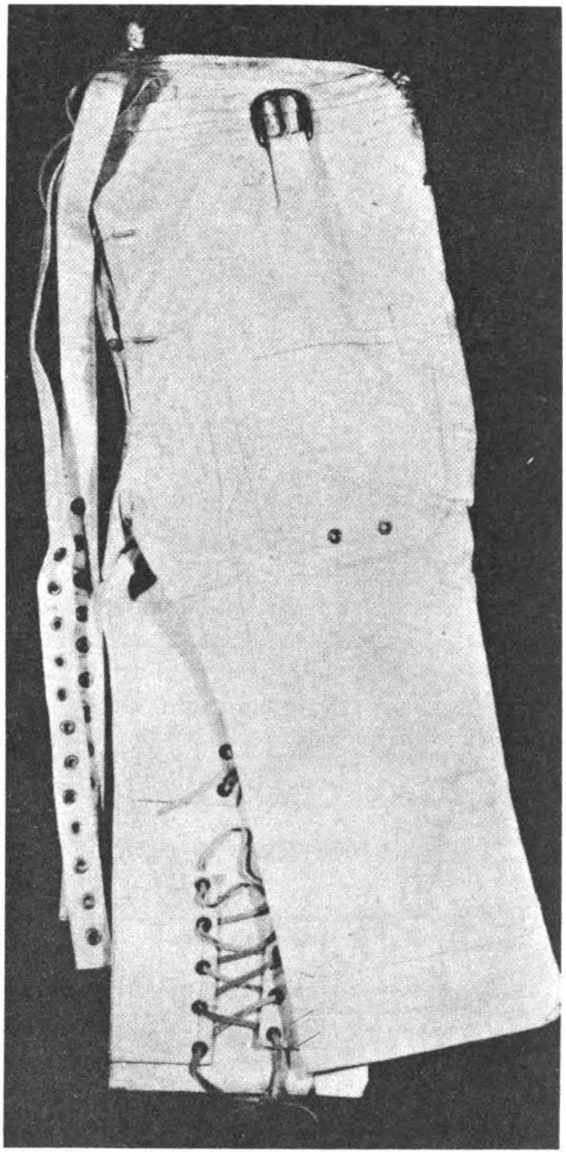

FIGURE 2–15.—Overalls.

Underwear

(34) The diver's underwear (fig. 2–16), consisting of undershirts, drawers, socks, and gloves, is made of 100 percent pure wool and, together with the diving dress, provides protection against the cold water. Frequently the underwear will be worn over the ordinary clothes, or several sets of underwear will be worn, depending on the temperature and the individual diver's preference. At least one set of underclothing should be worn to prevent the body from being chafed or bruised from the div-

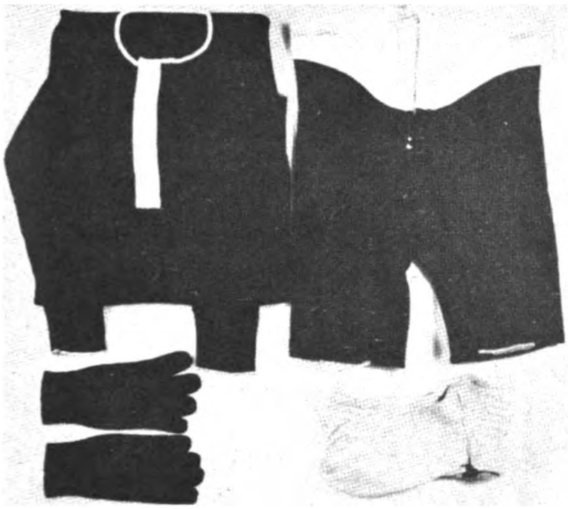

Figure 2-16.—Diver's underwear.

ing dress. It has been found that, when the diver is working moderately hard, one set of underwear will, under average conditions, provide the necessary insulation and warmth. Under more extreme conditions of cold, two sets of underwear will be satisfactory. In many places, thermal underwear is used instead of wool.

(35) The underdrawers are available in sizes 36, 38, and 40, and the undershirts in sizes 38, 42, and 44. The gloves and socks are supplied in medium sizes. In addition, size 42 and 44 underdrawers and size 36 and 40 undershirts are stocked in limited quantities. The underwear should be washed and allowed to dry thoroughly before being stored. Woolens will stretch under their own weight when wet and should not be hung on a line but placed on a flat surface for drying. When not in use, the woolens should be stowed in larvicide, such as naphthalene, and kept tightly wrapped in paper.

Belt

(36) The weighted belt (fig. 2-17) provides the necessary negative buoyancy to overcome the positive buoyancy of the helmet and diving dress when it is moderately inflated. The weight of the complete belt is approximately 84 pounds;

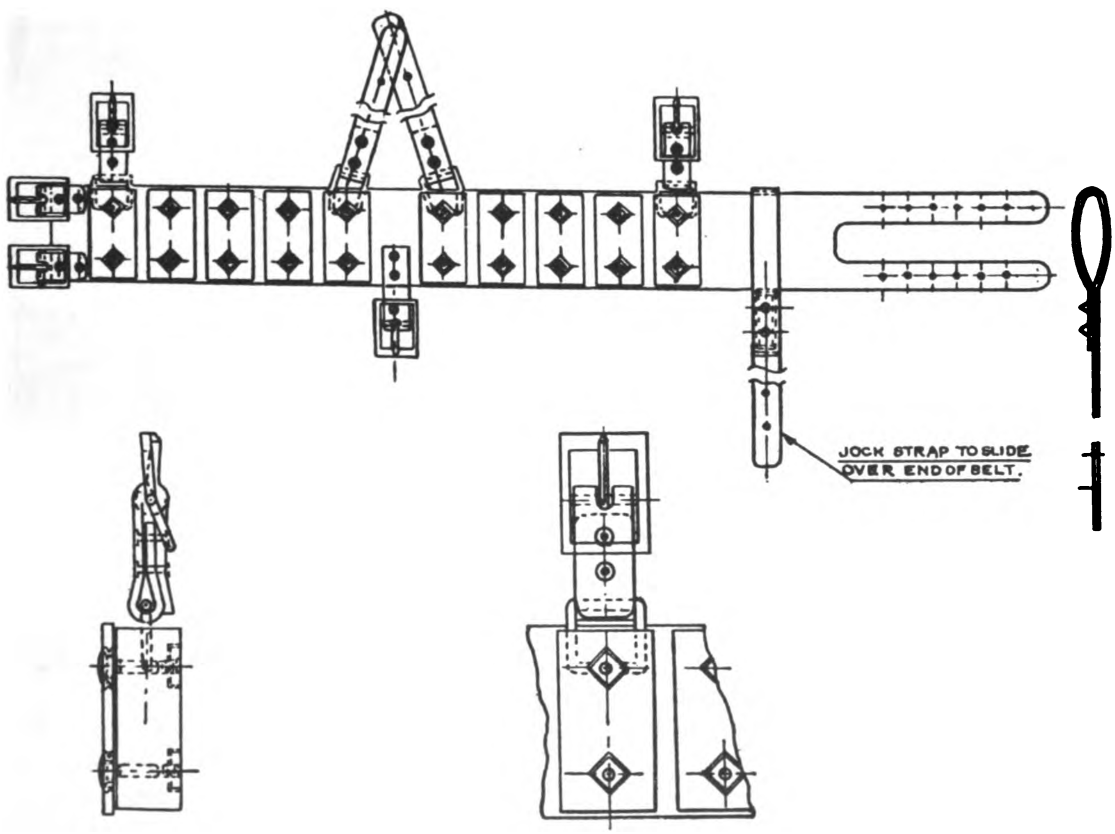

Figure 2-17.—Diver's weighted belt.

however, the weight can be varied as desired by adding or removing the individual 7½-pound lead weights. Metal strap fittings are cast in four of the weights and are set at angles to give the proper lead to the shoulder strap which passes over the helmet breastplate and crosses in the back and front so as to counteract any tendency the belt may have to shift.

(37) The jockstrap is provided for the dual purpose of preventing the helmet from rising over the diver's head, as it would if the dress were permitted to elongate due to overinflation, and to hold the belt in its proper location.

(38) To protect the belt leather, it should be given a coat of neat's-foot oil, well rubbed in so that it will not be disagreeable to handle. Because leather used in water will soon become dry and hard, the frequency of applying oil will depend on how frequently the belt is used. Deterioration of leather is not always discernible from visual examination; consequently, the belt strap, including the shoulder and jockstraps, should be tested for tensile strength. This may be accomplished by securing a regular diving belt buckle to the overhead, run the strap to be tested through the buckle; then have a man who weighs about 160 pounds gradually put his entire weight on the strap which will withstand the load if in a satisfactory condition.

Shoes

(39) The diver's shoes are used in conjunction with the weighted diving belt to overcome the positive buoyancy of the inflated diving dress and helmet, and to give stability to the diver.

(40) The standard weighted shoes (fig. 2–18) consist essentially of a lead sole, hardwood upper sole, either leather or canvas upper, lacing cord and leather straps for holding the shoe in place, and a protective brass toe clip. The shoes weigh approximately 35 pounds per pair.

(41) The lightweight diving shoes (fig. 2–19) are essentially the same as the standard weighted shoe, with the exception that a brass sole is used in lieu of the lead sole, and the weight of a pair is approximately 20 pounds. The use of the lightweight diving shoes will depend on the dress inflation and the individual diver's preference.

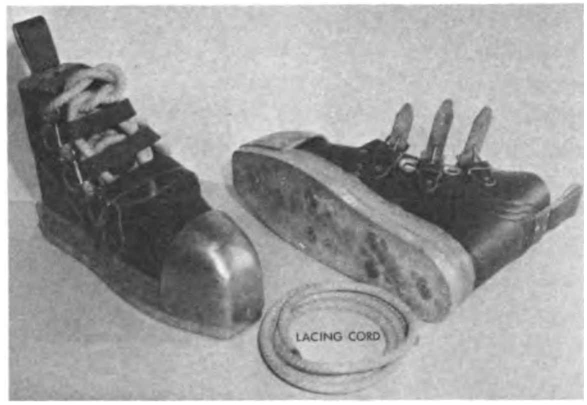

FIGURE 2–18.—Standard shoes.

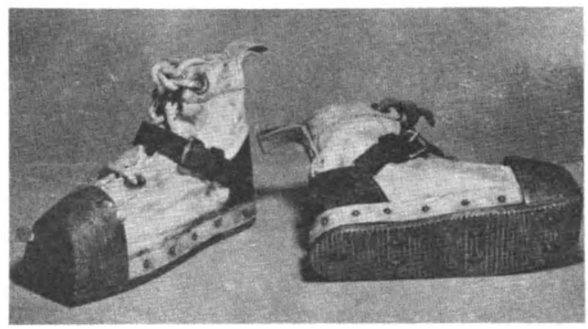

FIGURE 2–19.—Lightweight shoes.

Knife

(42) The diver's knife (fig. 2–20) is made of a tough tool steel and consists of a bayonet-shaped blade with one cutting and one saw edge, a metal sheath, hardwood handle, and a leather strap. The use of the term "knife" is misleading, as the instrument is actually a utility tool for prying, hacking, sawing, or cutting such material as wood, wire, or manila rope and sheet metal. As such, the knife represents a compromise of the individual features that go to make up the knife.

(43) The knife sheath is made of brass, cylinder shaped with a conical bottom. The top of the sheath has a wide-mouth opening to facilitate placing the knife in the sheath. A hole is drilled in the bottom of the sheath to permit drainage. A leather strap is used to fasten the sheath to the diver's belt. If the knife is to be stowed for any extended time, the sheath should be filled with grease to prevent the steel blade from corroding. When the knife is being used

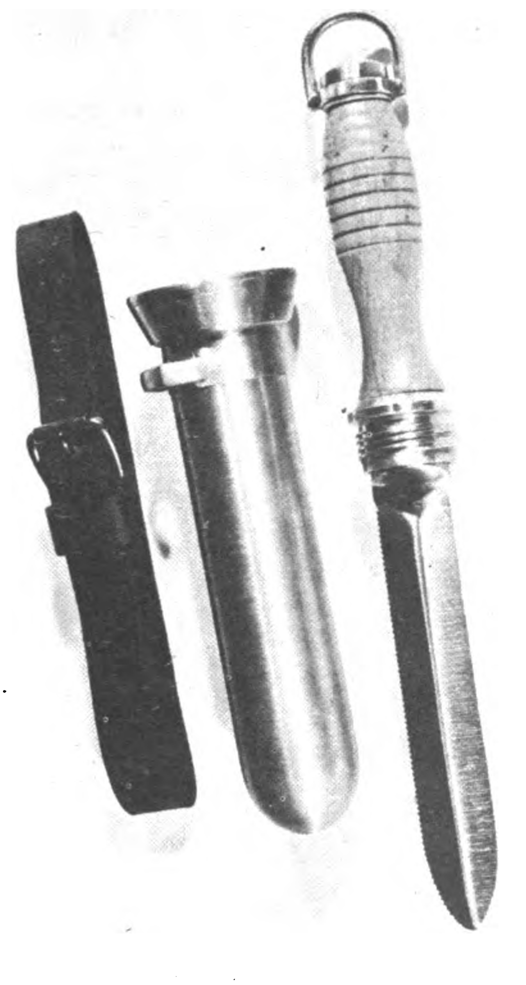

FIGURE 2–20.—Diver's knife.

frequently, it should be covered with a thin layer of grease.

Air Hose

(44) The diver's air hose (fig. 2–21) is a sinking type, having an internal diameter of one-half inch and an external diameter of $1\frac{1}{16}$ inches. It is constructed of a vulcanized-rubber tube reinforced by three plies of braided cotton laid on the bias to prevent the hose from wiggling, twisting, or turning while under pressure. The hose is furnished in two standard lengths—50- and 3-foot lengths. The 50-foot length of hose connects the surface air supply to the air-control valve. The 3-foot length of hose connects the air-control valve to the air-safety nonreturn valve on the diver's helmet. A special $3\frac{3}{4}$-foot length of hose is used for this purpose when helium-oxygen helmets are being used.

(45) When manufactured, diving hose is required to withstand a working pressure of 500 psi and a proof pressure of 1,000 psi held for 30 seconds. In addition, representative lengths are required to withstand a burst pressure of 2,000 psi instantaneously. In connecting the lengths, it should be remembered that the hose nearest the diver will be subjected to the least difference in pressure and, therefore, if there is any preference, the best hose should be on the end nearest the surface.

(46) The use and stowage of the diver's air hose should be governed by the following:

(*a*) Hose more than 5 years old shall not be used as diving hose. Submarine-rescue vessels (ASR) shall not use hose more than 3 years old.

(*b*) Diving hose in store more than 2 years should be surface inspected and hydrostatically tested to 75 percent of the working and proof pressures indicated above for new hose. In addition, one length of hose, selected at random from each lot of the same date of manufacture as representative of the lot, should be subjected to the burst test (75 percent of the 2,000-psi test). Hose that has been subjected to bursting tests should never be used for diving purposes.

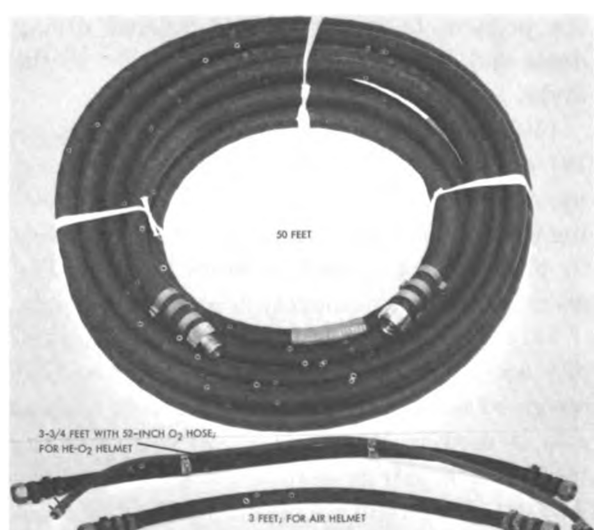

FIGURE 2–21.—Air hose.

(47) When diving air hose is requested, the issuing activity should furnish the receiving activity with a copy of the report of the last test made on the hose. Hose received without this report should not be placed in service until the report is received. However, if an emergency requires the use of the hose before a test report is received, it may be so used if it is retested by the ship.

(48) On receipt, and every 6 months thereafter, diving air hose shall be visually inspected and checked to insure that the clamps are tight. Diving hose in service shall be hydrostatically tested when it is 3 years old and retested every 6 months thereafter to 750 psi, with a concurrent elongation load of 250 pounds on the couplings held for a period of 1 minute. If hydrostatic tests cannot be made, the hose shall be subjected to a 350-psi air-pressure test, with a concurrent elongation load of 250 pounds on the couplings held for a period of 1 minute. If facilities are not available to conduct the required tests and it is necessary to use the hose, it should be subjected to an air pressure of at least 100 percent greater than the maximum pressure that will be applied to the hose topside and held for 10 minutes. An inspection shall be made to insure that the clamps are tight.

(49) The ends of each length of air hose are capped with a rubber compound to give the ends a smooth and watertight finish. Except in an emergency, the hose should not be cut because the uncapped sections permit water to permeate along the braid and inner tube of the hose, thus forming bubbles which weaken it.

(50) When coupling lengths of air hose together, a leather washer should always be placed in each female coupling. The air hose should not be coupled directly to the air supply but to the oil separators. If a long length of air hose has been in use, moisture is sure to have accumulated in it. Therefore, 50-foot sections should be separated and drained before stowing. Before using new hose, it must be thoroughly cleaned inside by running fresh water through it and then blowing it dry. Hose carried on racks should also be blown out periodically and before use to remove soapstone powder and other deposits.

(51) The various types of air-hose fittings are shown in figure 2–22. The ends of each 50-foot length of hose are fitted alternately with male and female couplings. The ends of the 3-foot length of hose are fitted with female couplings. When fitting the air-hose couplings

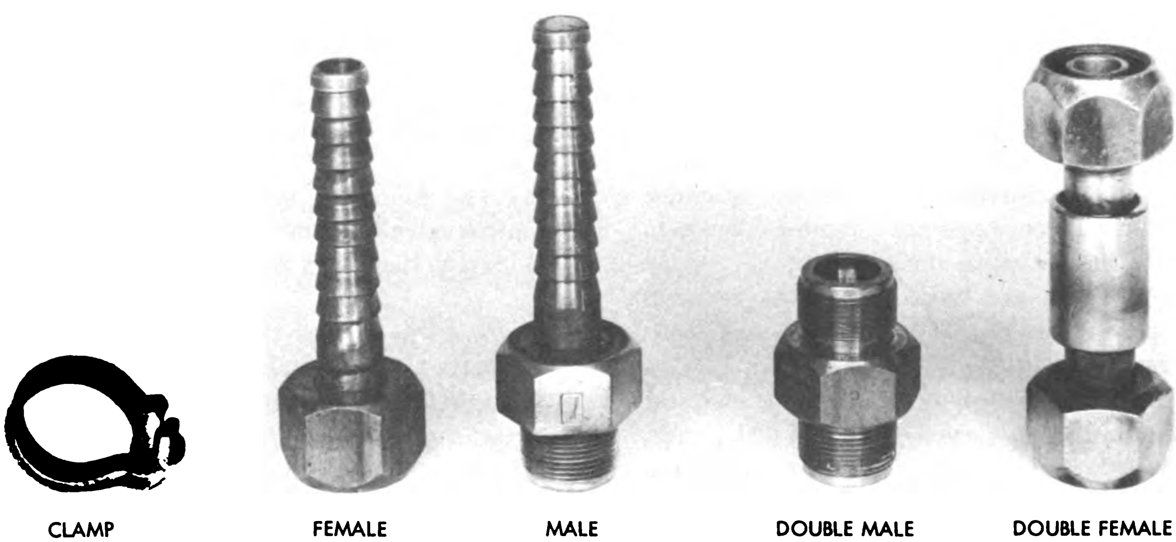

FIGURE 2–22.—Air-hose fittings.

on the hose, the following procedure is recommended:

(*a*) Slip three clamps over the end of the hose.

(*b*) Coat the shank of the couplings with rubber cement and clamp in a vise. When attaching a female coupling, it should be assembled to a male coupling, its shank coated, and clamped in a vise.

(*c*) The hose is then forced over the coupling shank until it is against the shoulder of the coupling.

(*d*) The first clamp is placed in position and set in a vise. Tighten the vise until the clamps are compressed, bringing the clamp screw holes in line. The clamp screw is then screwed in place and the operation repeated on the next clamp.

(52) Because the shank of the coupling is slightly larger in diameter than the bore of the hose and the clamp is smaller than the external diameter, forcing the hose onto the corrugations of the shank and gripping tightly with the clamps will insure the coupling a firm hold on the end of the hose. A firm hold is absolutely necessary in view of the serious consequences that would result should a coupling pull out of the hose when a diver is under water. The joints between male and female parts of the hose coupling are made watertight by leather washers. Double male and female standard air-hose couplings are provided for use when it is desired to make a special connection; for example, when the alternations of male and female connections are not continuous. Wherever special couplings such as double-male or double-female couplings are used, they should be placed in the line of air hose so they will not be under water. Such couplings are intended for use in making surface connections.

(53) There are two diving hose reducers (adapters) furnished for making special connections (fig. 2–23). The S-reducers have a standard 3/4-inch pipe thread on one end and a standard diver's air-hose thread (1$\frac{1}{16}$-inch, 17 threads) on the other. They are used for making connections from an air source having a standard pipe thread to a diver's air-hose fitting. The T-reducers have a standard diver's air-hose thread cut on one end and a torpedo air-flask thread (1$\frac{1}{8}$-inch, 14 threads per inch) on the opposite end. The T-reducers are used for connecting the diver's air hose to the torpedo charging lines when submarine high-pressure airflasks are used as a diver's air supply.

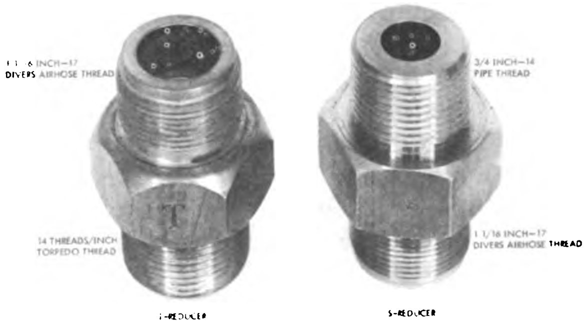

FIGURE 2–23.—Hose reducers (adapters).

Air-Control Valve

(54) The diver's air-control valve (fig. 2–24) is a needle valve design and is used to control the flow of air to the diver's helmet. The valve consists of the body, valve stem, stuffing box, packing gland, capnut, handle, and the link and eye pad. The body of the valve is a brass casting with standard male air-hose threaded inlet and exhaust connections. Attached to the lashing eye of the body is a link and eye pad for securing the control valve to the bastard stud on the left side of the helmet breastplate. The body-valve seat and the stem seat are ground at a 60° angle. The valve stem and the stuffing box are joined by $\frac{5}{8}$-inch, 8-Acme threads of sufficient length so that when the valve is in a completely open or closed position, referring to figure 2–24, a minimum of two threads are engaged.

(55) The following method of assembling the control valve is recommended:

(*a*) Screw the valve stem into the stuffing box.

(*b*) Place the copper ring washer into the groove on the top of the valve body.

(*c*) Insert the valve stem into the body and screw the stuffing box up tight with a wrench. The valve stem should not be in contact with the body while the stuffing box is being drawn up tight.

(*d*) Insert the first lead packing ring over the valve stem.

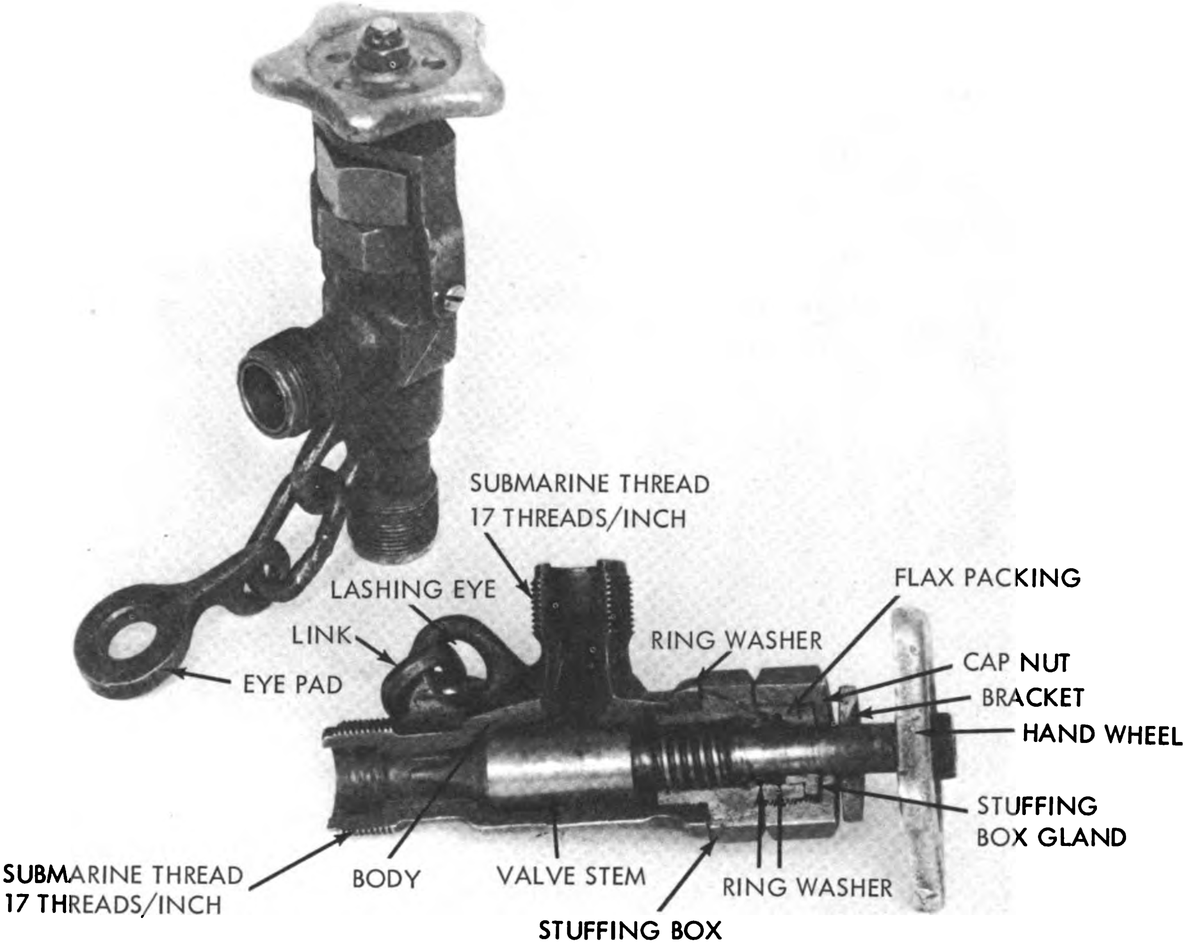

FIGURE 2-24.—Air-control valve.

(*e*) Take several turns around the valve stem with the flax packing, and insert the second lead packing ring.

(*f*) Insert the stuffing box gland and screw the capnut into position.

(*g*) The bracket is secured by screws to the valve body to prevent the capnut from backing off.

(*h*) Place the valve handle, stem nut, and cotter pin in place. The valve handle is designed so that it can be readily grasped when wearing the diver's gloves.

(56) The packing of the diver's air-control valve is very important and should be carefully adjusted so that the valve works stiffly enough to prevent its being opened or closed accidentally but is sufficiently free to be readily manipulated by the diver, even though he is wearing the heavy divers-tenders gloves.

2.1.3 DESCRIPTION AND CARE OF LIGHTWEIGHT DIVING OUTFIT

Lightweight Diving Outfit

(1) The lightweight diving outfit (fig. 2-25) consists of the following items: weighted belt, rubberized fabric dress, and mask (see also fig. 2-3).

Weighted Belt

(2) To compensate for the additional buoyancy gained when using the diving dress and underwear, a leather weighted belt (fig. 2-26) is used. The weight of the belt may be varied up to 45 pounds by removing or adding weight depending on the amount of clothing worn, water condition, and the diver's preference. The belt buckle also permits the belt to be discarded rapidly in the event the air supply is lost. To permit the belt to be discarded in an emergency,

Figure 2–25.—Lightweight diving outfit.

the shoulder straps should be crossed only in back and under the metal clamp. When diving with the mask alone, use either the standard cartridge belt (fig. 2–27) with a quick-release-type buckle and lead weights cut to fit the pockets, or the belt used with the self-contained diving outfit.

Lightweight Diving Dress

(3) The dress (fig. 2–28) is made from a rubberized fabric of a two-ply construction, the outer ply of cotton twill and the inner ply of cotton cloth known as airplane cloth; they are bonded together by a rubber compound. The dress is made in one piece, with a hood cemented

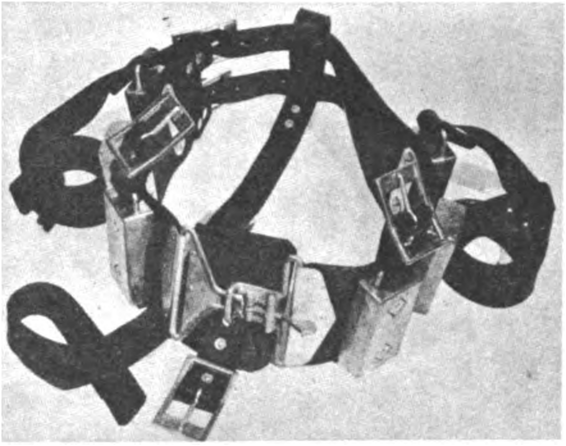

FIGURE 2-26.—Leather weighted belt.

to the body of the dress, and covers the entire body with the exception of the face opening and hands. Entrance to the dress is made through a cylindrical opening in the back of the dress. In dressing, the diver enters through the back opening, feet first, pulls the lower portion well up around the waist, and then, bending forward, inserts arms and head. If cuffs are used, soap should be applied on the hands before dressing to facilitate putting the hands through the cuffs. If the diver's wrist is small, an elastic tubing should be used over the edge of each cuff to insure watertightness.

(4) After the entrance is made, the back opening is made watertight by gathering the

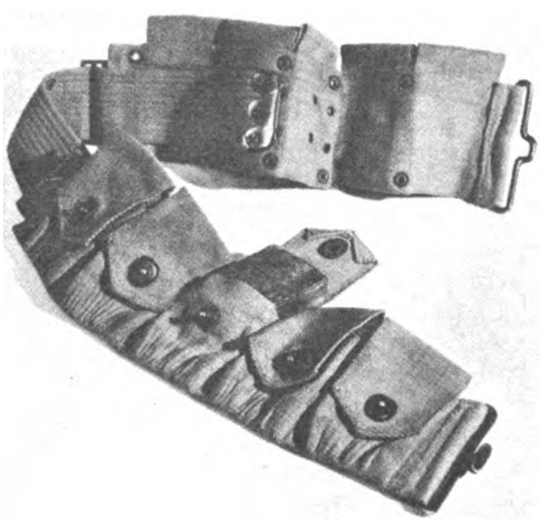

FIGURE 2-27.—Rifle-cartridge belt.

FIGURE 2-28.—Lightweight diving dress.

material together and using the metal clamp. The following method of making a watertight seal is recommended: fold the material into approximately 2½ pleats; then fold across the middle to make a 5-ply bundle; finally the bundle is doubled over and inserted in the metal clamp. The clamp should be positioned so that the thumbscrew is on the bottom of the fold. After the watertight seal is made, the hood should be laced up the back so that it will fit as snugly as comfort will permit to reduce the hood volume to a minimum.

(5) Cemented to the front of the dress hood is a thin rubber gasket which has a face opening extending from the forehead to the chin. The gasket should be placed under a slight tension to eliminate wrinkling, which would cause leaks when the mask is put on. The face opening of the gasket may be enlarged to fit the face. However, if the opening is enlarged, the rim should be folded over approximately one-fourth inch and cemented to prevent the gasket from tear-

ing. The method of replacing the face gasket is found in appendix C.

(6) As stated before, the principle of operation of the lightweight equipment is based on the elimination of air from the dress. To dispose of any air in the dress, an exhaust valve is placed in the top of the hood. The dress is improperly adjusted if accumulated air is prevented from entering the hood section from which it can be exhausted through the valve. To release the air trapped in the dress, the diver should enter the water slowly enough to permit the air in the suit to escape through the exhaust valve.

Hose

(7) Standard $\frac{5}{16}$-inch oxygen hose in 200-foot lengths is used to supply air to the diver. The hose is furnished with two female couplings and the necessary double-male fitting. When manufactured, the hose is required to withstand a working pressure of 250 psi and and a bursting pressure of 700 psi maintained for 2 minutes. Hose in diving service shall be visually inspected on receipt, rechecked every 6 months thereafter to insure that the couplings are tight. It shall be subjected to an air-pressure test of 125 psi held for a period of 1 minute when it is 2 years old, and retested every 6 months thereafter. An inspection shall be made to insure that the couplings are tight. Hose more than 5 years old shall not be used as diving hose. In an emergency, and when the only diving hose available does not have a date stamped on it, the following test should be made: $2\times(D\times0.445+50)$. It is recommended that the hose be of continuous length.

Mask

(8) The essential parts of the mask (fig. 2–29) are the copper frame, rubber seal, plastic front window, inlet valve, exhaust valve, and head harness. The copper frame and rubber seal are molded in a shape that provides a seal with the dress hood facepiece and which provides a broad field of vision with minimum distortion. The mask complete with fittings does not include the air-control valve or nonreturn valve, which are furnished as separate items.

(9) Air enters the mask through the inhalation valve on the side of the mask. When the inhalation-valve handle is pointing toward the rear, air enters directly from the air line into the mask. The other valve position was once used with a breathing bag. It should be capped and *not used*. The section of the inhalation valve on the inside of the mask is a rubber flapper valve that prevents air in the mask from escaping back into the breathing bag.

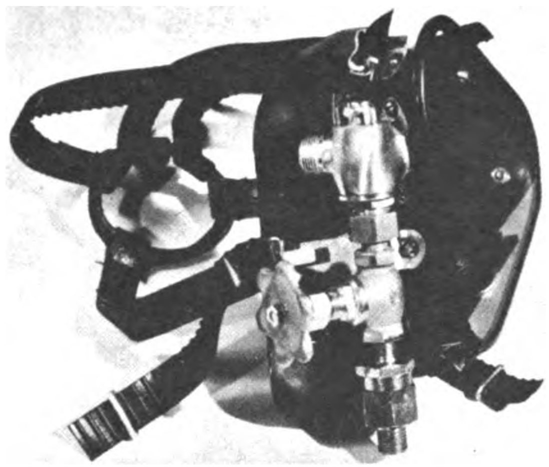

FIGURE 2–29.—Mask.

(10) On the opposite side of the mask from the inhalation valve is the exhaust valve, consisting of a rubber disk that opens during exhalation and closes by water pressure at the end of the exhalation period. The rubber disk is held in place by an adjustable stem that is usually set in the proper position. However, if the entire mask seems to bounce or gives a "water-hammer" effect, the valve stem should be readjusted. The mask is held in position by an adjustable head harness.

(11) Although the mask is reasonably rugged, care should be taken in handling and storing. The mask should be kept away from sunlight, heat, and oil when not in use and should be thoroughly cleansed with fresh water and dried before storing.

Control Valve

(12) A modified standard commercial globe valve is used to control the quantity of air entering the mask (fig. 2–30). The valve is attached to the inhalation valve on the mask. It is placed to maintain a fixed position, and so it will be in the most accessible place for controlling the

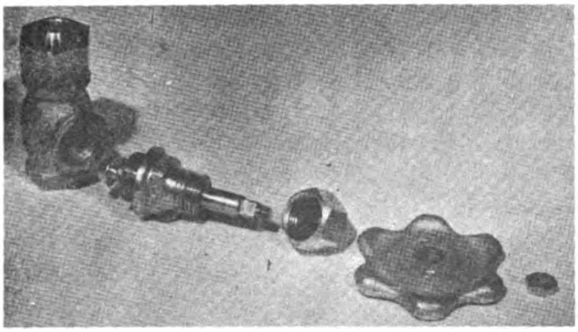

FIGURE 2-30.—Control valve.

air supply where the supply is least likely to be closed by accidentally hitting the valve handwheel. The control-valve handwheel should be maintained sufficiently tight by means of the packing-gland nut to prevent the handle from turning loosely or too readily.

Nonreturn Valve

(13) The nonreturn valve (fig. 2-31) is located between the air-control valve and the air hose. The purpose of the nonreturn valve is to prevent the diver from being injured by squeeze should the air hose burst or the supply system become so seriously damaged that air pressure within the mask is not sufficient to maintain a pressure equilibrium. Under either condition, the air pressure to the hose would decrease suddenly and, should there be no nonreturn valve, the compressed air in the mask would escape through the air hose, causing the pressure within the mask to fall below the external pressure and resulting in a squeeze. Because the mask is rigid, the effect of the greater external pressure would be to squeeze the diver's face into the mask. This condition would have serious results.

(14) The use of the nonreturn valve is so essential that no diving, regardless of depth, should be undertaken unless there is a nonreturn valve operating satisfactorily in the line. A simple method of determining whether the valve is operating satisfactorily is to attempt to blow smoke through the valve in the direction opposite to the normal flow of air (2.1.2(8)).

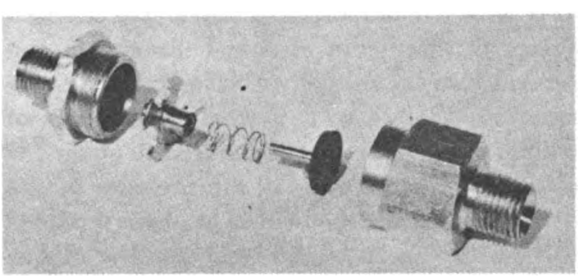

FIGURE 2-31.—Nonreturn valve.

Spares

(15) Spares consist of cement, patching cloth, face gasket, head harness, dress, and mask flapper valves (fig. 2-32).

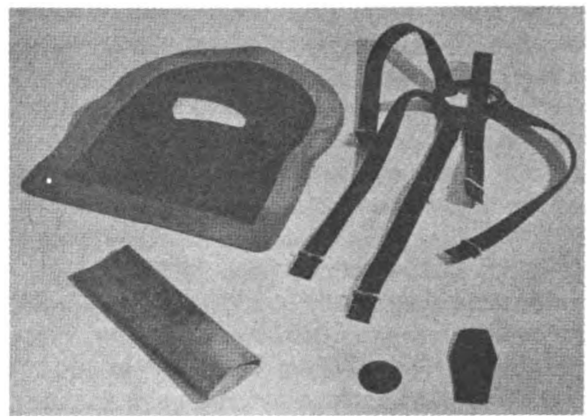

FIGURE 2-32.—Spare parts.

Lifeline

(16) The lifeline should be made up on board from 1¼-inch manila rope or sisal rope of equal strength. The lifeline is married to the diver's hose to facilitate tending and to prevent straining the hose during diving operations. The diver's end of the lifeline is secured around the diver's chest, with sufficient slack in the air hose leading to the mask so that any strain on the lifeline will not tend to pull on the mask. The line should not be connected to or looped around the weighted belt and should be arranged so that the belt might be released without interfering with the hose or lifeline. The line serves three purposes: first, to remove any strain from the air hose; second, to allow tending and to assist in descent and ascent; and, third, to maintain communications with the diver.

Other Equipment

(17) The remaining items—cuffs, gloves, knives, overalls, shoes, and underwear of the lightweight diving outfit—are the same as those furnished with the deep-sea diving outfit previously described.

Maintenance of Equipment

(18) Every effort shall be made to keep the diving apparatus in repair and ready for immediate use. With this in mind, the following general recommendations on the maintenance of equipment are made.

(19) Diving apparatus should not be stowed in compartments below the waterline or in places of difficult access in time of emergency. All chests of diving apparatus should, when sufficient space is available, be habitually stowed under cover, away from steampipes or excessive heat. When it is necessary to keep the equipment in the open and exposed to the weather, suitable canvas cover should be provided and used to protect the outfit.

(20) Spare parts of diving apparatus not required for immediate use shall be kept in suitable storeroom space and, when drawn for use, shall be replaced by new parts immediately.

(21) Leather articles used in water soon will become dry and hard and are likely to crack unless properly cared for. Finished leather contains a certain amount of oil and grease and, when this is washed out, the leather loses its flexible quality and shows signs of deterioration. Occasionally the leather parts of diving apparatus should be given a coat of neat's-foot oil, well rubbed in so the articles will not be disagreeable to handle. To treat leather properly with neat's-foot oil, place the article to be treated in as flat a position as possible. Then soak a rag in oil and apply one coat of oil at a time until the oil soaks through on the other side. Do not attempt to apply the oil from both sides at once, and do not submerge the article in the oil.

(22) All metal parts of diving apparatus should be kept free of rust or verdigris, in efficient working order, protected from injury. Special precautions are to be taken with valves, valve seats, and like parts. Parts not kept painted, polished, or galvanized should be kept lightly coated with oil.

(23) As oil or grease are especially destructive to rubber, parts of diving apparatus composed of rubber, such as dress, hose, and cuffs, must be protected from oil or grease in any form. Diving dresses and other parts made of rubber with cloth coverings or cloth insertions must not be put away while damp or wet. Rubber materials, when folded, acquire a permanent set at the bends and later, when used, are likely to crack or break at these points. Such materials should so far as practicable be stowed without folding. The instructions for making repairs to diving dresses apply also to other rubber or rubberized materials.

(24) The service life of rubber products used in diving is definitely limited by physical characteristics inherent to the material. To obtain maximum service from such material, including diving hose, it should be used regularly throughout its useful life and not allowed to remain idle during intervals of employing newer equipment. New equipment should be procured to replace that which has become unserviceable or has reached an age limitation as an orderly, routine process, but it should be held for replacement and not used until so needed.

(25) All cotton and woolen goods should be kept clean, dry, and in repair. When not in use, they should be stowed with a larvicide such as naphthalene and kept tightly wrapped in paper. Dirty woolens should be washed with soap and tepid fresh water, thoroughly rinsed, and carefully dried.

2.1.4 DESCRIPTION AND CARE OF HELIUM-OXYGEN DIVING OUTFIT

Helium-Oxygen Diving Helmet

(1) The helmet (fig. 2–33) used in helium-oxygen diving is a modified standard diving helmet. The principal changes involve the installation of a means of conserving the helium-oxygen mixture by recirculating it through a carbon dioxide absorbent. Essentially the recirculating device draws the carbon-dioxide-laden atmosphere from the helmet, forces it through a chemical absorbent, and returns it to the helmet with the carbon dioxide removed. In this way, normal expenditure of helium-oxygen mixture is reduced to about 1/2 cubic foot per minute at the pressure of the dive. In addition, the helmet has been modified to take the special goosenecks for the carbon dioxide absorbent canister and electrically heated underwear (no longer used). A second-

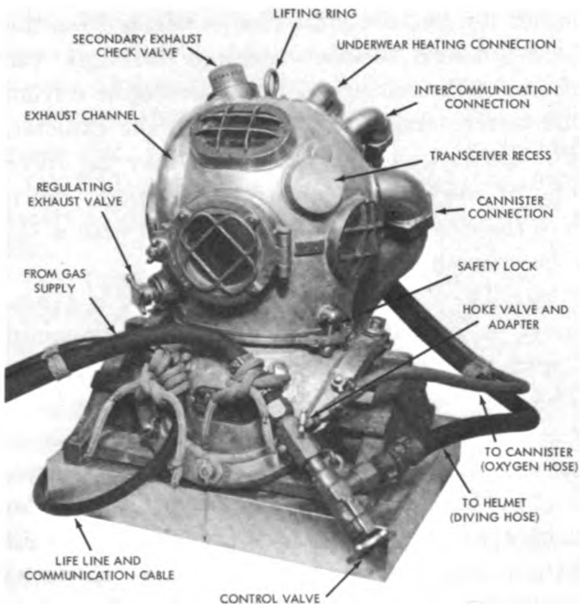

FIGURE 2–33.—Helium-oxygen helmet (front).

ary exhaust check valve has been installed on the exhaust channel to prevent accidental flooding, and a duct from the canister discharge opening improves gas circulation within the helmet. The modified helmet with breastplate and canister weighs about 103 pounds as opposed to 56 for the standard helmet and breastplate.

Recirculating Device

(2) The recirculating device is shown in figure 2–34. The connection to the aspirator or circulator consists of the screen retainer assembly which is screwed directly into the high-pressure nozzle fitting. The screen retainer assembly contains a 100-mesh bronze screen. It is important to keep this strainer in good condition and clean so that it will screen out particulate matter blown along the hose and prevent plugging of the high-pressure nozzle, and so that such matter does not accumulate to obstruct the flow of gas. The high-pressure nozzle fitting is threaded into the aspirator body with a metal-to-metal joint; no packing is used. It can be removed for cleaning with a ¾-inch wrench.

(3) The high-pressure nozzle is secured into the aspirator body and projects into the throat of the venturi. The orifice of the nozzle is so proportioned that, with 100-psi differential pressure, a volume of gas that contains sufficient oxygen to replace that consumed by the diver is introduced into the helmet in a given time. Simultaneously, the movement of the gas mixture

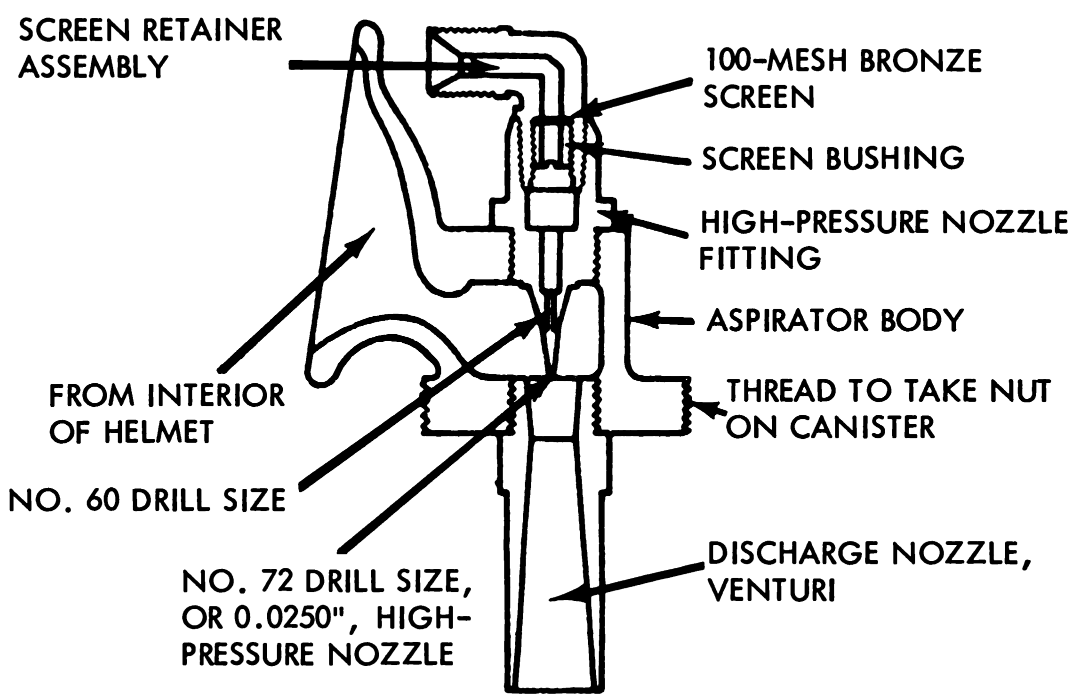

FIGURE 2–34.—Recirculating device.

through the nozzle draws the atmosphere from the helmet and forces it through the carbon dioxide absorbent in the canister and then back to the helmet after purification. Any excess gas pressure that builds up escapes through the exhaust valve. By this means, the helmet is given sufficient ventilation and the amount of gas that is required is only about one-fifth of that used in the standard open-circuit method of ventilation.

(4) As the nozzles are machined to extremely accurate dimensions, they must be handled very carefully. The relative position of the nozzles must also be exactly as designed. A nearly invisible scratch or a tiny bit of foreign matter around the nozzles will alter the flow of the gas and will result in inadequate ventilation of the helmet. The dimension of the jet orifice is 0.025 inch, or No. 72 drill size. Each time a helmet is used, inspect the strainer and nozzles. Insure that the high-pressure nozzle is clean by blowing filtered high-pressure air or oxygen through it and by running a No. 72 drill-sized wooden or plastic rod through it from the high-pressure side. A No. 72 drill inverted in a pen vise usually is used.

(5) The jet produces a low rumbling noise. Any change in this sound may indicate that the recirculating system has failed. The discharge nozzle is a venturi tube. The jet of gas from the high-pressure nozzle rushing through the throat of the venturi sucks the atmosphere from the helmet and forces it through the canister. The discharge nozzle is screwed into the lower side of the aspirator body and projects down into the canister. It can be removed with a ⅞-inch wrench.

(6) The carbon dioxide absorbent is essentially a noncaustic, barium lime compound known commercially as Granular Baralyme. The granules contain barium, calcium, and potassium hydroxides. This absorbent replaces the extremely caustic Shell Natron for all use.

(7) The canister (fig. 2–35) is attached to the helmet with two large nuts that can be turned with a 3-inch wrench. Neoprene or Koroseal washers inside the nuts make the connection watertight. In assembling the recirculating system, it is essential that all connections be completely tight to avoid loss of gas and to prevent water from reaching the Baralyme.

(8) *A. Canister packing:*

About 6 pounds of Granular Baralyme can readily be packed in this canister. The packing method as outlined below is offered as one of tested and proven worth:

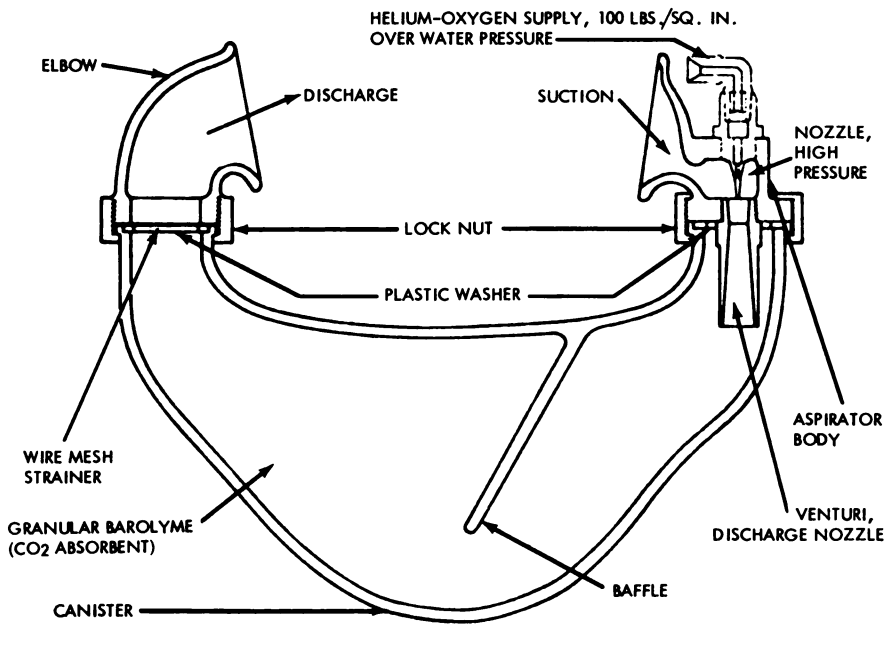

Figure 2–35.—Canister.

(*a*) Fill the canister from both sides, pouring directly from the stock container, making sure to pour off dust from the top of the container.

(*b*) Fill the left side until level with the screen rim.

(*c*) Fill the right (venturi) side approximately to within 3 to 3¼ inches of the canister rim.

(*d*) Tap lightly on the deck or with a mallet. Vigorous shaking or pounding tends to fracture the granules, causing dust to accumulate.

(*e*) Discard the last 2 inches of Baralyme in the stock container, because powder produced during shipping handling probably will be close to the bottom of the container.

(*f*) A properly prepared and filled canister will accommodate at least 6 pounds of Granular Baralyme.

B. Significance of packing procedures:

The canister-packing sequence detailed above was developed gradually and was altered from time to time as experience in the handling of Granular Baralyme mounted and as the potential problems became known. It is suggested that attention be maintained regarding the precautions listed for Baralyme powder, dust, or small fragmented particles. Once in the canister, these could be picked up by the circulating gas stream and either filtered out onto the screen, thereby occluding it, or passed through the screen so that the circulating particulate matter would be within the helmet itself. A more urgent reason may be cited to favor routine examination of the contents of each freshly opened carton, with constant attention to the gross physical state of all Baralyme placed within the canister: if a manufacturer's lot of the material was sufficiently softer or less dense than normal, the chances for caking or congealing of powder and soft granules with water (forming solid masses of absorbent) would be facilitated.

C. CO_2 elimination efficiency and duration:

The deep-sea helium-oxygen outfit is a semiclosed rig insofar as gas supply and utilization govern, and is a recirculating apparatus with regard to purification, dilution, and resupply of respired gas. In a theoretical sense, one may assume that each inhaled breath represents a mixture of fresh supply gas and recirculated, more-or-less CO_2-free canister gas. The supply flow, conventionally referenced to supply pressure, must satisfy the ventilatory demands of the situation. In addition, this supply gas functions to dilute the CO_2-containing helmet gas and to provide flow through the canister. Absorption systems of the types more commonly employed for anesthesia apparatus and self-contained rigs are characterized by intermittent gas flow over the absorbent. During the very short postexpiratory pause of normal respiratory patterns, exhaled gas within the canister remains in contact with the chemical. Lacking this functional property, the He-O_2 canister system must utilize its recirculation volume potential so that more gas is exposed for chemical reaction. This is a less efficient CO_2 removal principle and it now has been mated to a less-reactive absorbent. Therefore, it is considered essential that the following procedures be assimilated into He-O_2 diving techniques:

(*a*) Maintain 100-psi supply pressure over bottom pressure for all working dives, regardless of depth.

(*b*) Overpressure of 50 psi should be used for the oxygen decompression stops.

(*c*) Long bottom times and hard work periods should be interrupted with ventilation periods.

(*d*) Water is a product of the Baralyme-carbon dioxide reaction. This water can be carried by the recirculating gas and can cause faceplate fogging and condensation which, therefore, do not indicate that CO_2 has accumulated within the helmet.

(*e*) Disregard the color shown by the indicator which may have been dispersed through the absorbent. It cannot be relied upon in determining the extent of completeness of absorption.

(*f*) The specified maximum total duration of a canister load is 3 hours. Adherence to this maximum usage will insure a 200-percent safety factor.

(9) The exhaust valve (fig. 2–33) is the standard air-regulating escape valve of the "nonblowup" type. The description, adjustment and maintenance instructions of 2.1.2 and appendix C apply except that the valve's initial setting is made so that the secondary valve-

spring follower disk (N) comes in contact with the sleeve when the adjusting wheel (G) is about 2½ turns short of the fully closed position. The exhaust channel is led over the top of the helmet and terminates in the secondary exhaust check valve (fig. 2–36). This secondary exhaust valve is a double-check valve. It should be disassembled prior to each dive and inspected for tightness and cleanliness. This is accomplished by removing the two threaded rings from the top of the valve. The lower ring is tightened by a special wrench and the upper by hand. Prior to stowing the helmet for any period of inactivity, the rubber valve diaphragms should be dusted with talcum powder to prevent sticking. Care should be taken to avoid contact of oil or grease with the rubber. During the dive, the exhaust valve is normally kept closed, the diver using the chin valve as necessary to regulate his buoyancy. This is the "circulate" condition. When ordered to "ventilate," the diver opens the control valve and holds

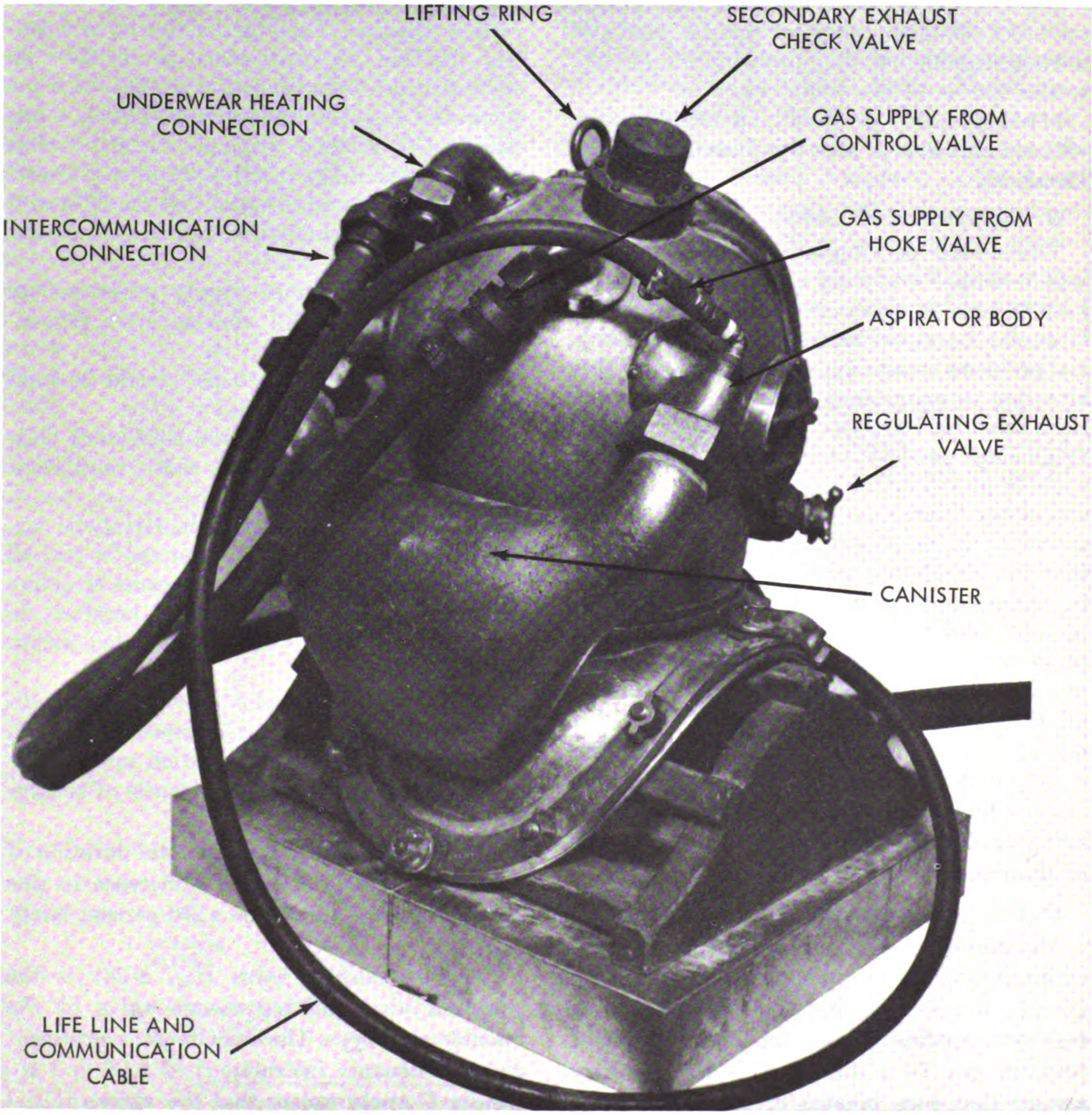

FIGURE 2–36.—Helium-oxygen helmet (rear).

the chin valve open. If it is necessary to "go on open circuit," the exhaust valve is used in the ordinary way and is opened as necessary to regulate ventilation.

(10) The helmet safety lock (fig. 2–33) has been shifted to the left front of the helmet so as not to interfere with the carbon dioxide absorbent canister. The spitcock, common to the standard helmet, has been removed to provide space for the helmet-locking device and to prevent possible loss of gas or entrance of water from leakage.

(11) The helium-oxygen venturi supply hose (fig. 2–33) is a 52-inch section of standard oxygen hose and is led from the Hoke needle valve on the control-valve adapter to the venturi. With this arrangement, the breathing medium is led to the venturi jet with the control valve closed. Should a sudden additional supply of gas be required, as for instance during the descent, the control valve can be opened to obtain an open-circuit flow similar to that in a conventional deep-sea outfit. The aspirator hose is secured to the 3-foot 9-inch length of regular diving hose. During the dive, the Hoke valve is kept fully open at all times to supply the helium-oxygen mixture to the venturi. It should never be closed unless the aspirator supply hose breaks or becomes disconnected.

(12) The control valve (fig. 2–33) is the standard type control valve with a hexagonal adapter carrying the Hoke valve attached to the supply side. During the dive, the control valve is kept closed except under the following conditions:

(*a*) To build up the pressure and volume of gas in the suit during the diver's descent.

(*b*) Whenever the diver suddenly requires more gas in the suit to regulate buoyancy.

(*c*) To supply gas or air to the helmet in the conventional way in case the recirculating apparatus fails. Use of the control valve in this manner is called "going on open circuit."

(*d*) To ventilate the helmet by replacing the gas in the dress with a fresh quantity of gas. The control valve and the exhaust valve are opened on the order "ventilate" and closed on the order "circulate."

(13) The air hose is the regular diver's air hose. The control valve and hose are attached to the breastplate in the usual way. The 3-foot 9-inch length of hose is led under the diver's left arm and to a standard safety nonreturn valve attached to the right gooseneck.

Submarine-Rescue Vessel Helium-Oxygen System

(14) The shipboard helium-oxygen system consists of a helium-oxygen and oxygen cylinder stowage rack, diving station supply manifolds, and associated volume tanks, valves, gages, and piping. The system is designed so that one of three breathing media—helium-oxygen, oxygen, or compressed air—can be supplied to the diver as required. The installations in different submarine-rescue vessels vary in details of design, but, in general, they all provide for stowage of approximately 100 gas cylinders and for diving 2 divers from each of 2 separate stations.

(15) The cylinders containing the helium-oxygen and oxygen gases are arranged in banks (fig. 2–37). They are arranged so that each helium-oxygen bank is loaded with a mixture containing a definite average percentage of oxygen. The cylinder valves are opened, and gas to be supplied to the diver can then be controlled by valves on each bank. The oxygen cylinders are arranged in their own banks. The stowage is so designed that cylinders in an exhausted bank can be replaced without interrupting gas supply to the diver.

(16) Helium-oxygen from the cylinder stowage rack passes through a high-pressure strainer and, in the installation shown in figures 2–38 and 2–39, through a pressure regulator to the volume tanks. These volume tanks number two for helium-oxygen and one or two for oxygen. Oxygen from the cylinder stowage rack passes through an oxygen pressure regulator before entering its volume tank(s). These piping systems include suitable valves, gages, and bypass arrangements. The volume tanks are tested to a pressure of 1,000 psi.

(17) Gas from the volume tanks then goes to the diving stations where pressure-regulating valves for controlling the pressure of helium-oxygen or oxygen supplied to the divers are located (fig. 2–40). Each of these diving station manifolds provides necessary piping, valves, and gages to supply either helium-oxygen,

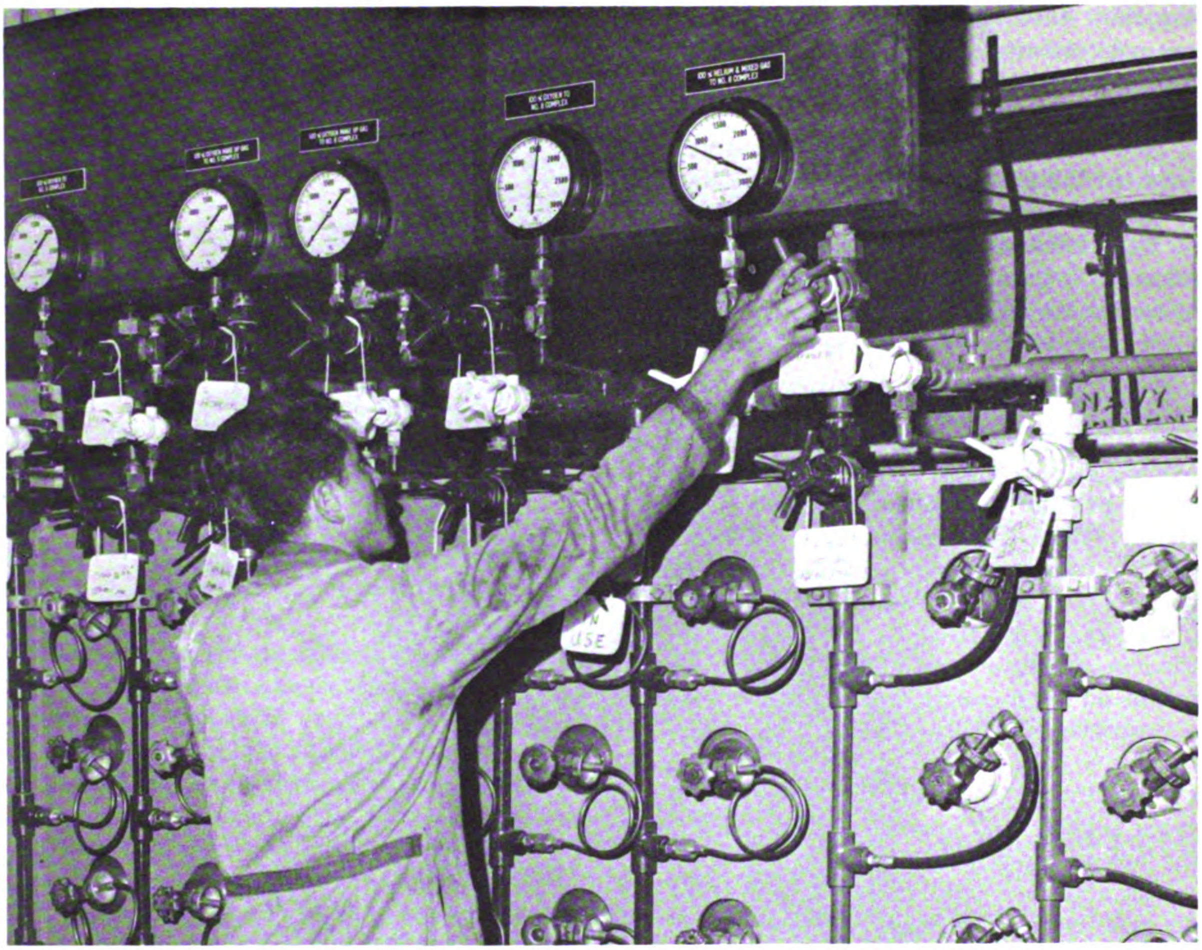

FIGURE 2-37.—Helium-oxygen stowage banks, Experimental Diving Unit.

oxygen, or air to one or two divers. It should be remembered that pressure regulation of the compressed air is at the source and not at the manifold.

Pressure Regulator

(18) The pressure-regulating valves (figs. 2-38 and 2-40), with their dome loaders, are used to regulate the pressure of helium-oxygen gas mixtures to that required by the diver. The valves are similar in construction to other diaphragm-operated regulators except that, instead of controlling the discharge pressure by means of spring pressure against the diaphragm, a dome over the diaphragm is charged to a suitable pressure by the dome loader. In case the pressure regulator does not operate correctly, it can be cut out of the system by cutout valves and the pressure controlled by means of a bypass valve. The pressure delivered by the regulator must be carefully adjusted to the correct over-bottom pressure for the diver. Too low a pressure would prevent proper functioning of the diver's recirculating system. This adjustment requires continuous changing of the dome loader setting while the diver is going down or coming up. An overpressure of 100 psi is required for most efficient operation of the equipment, and this pressure is maintained during the descent and time on the bottom. On the ascent, overpressure may be reduced to 50 psi at the oxygen stops. This pressure provides adequate ventilation for the remainder of the ascent.

(19) The most likely causes of derangement of the regulator are failure of the diaphragm and worn or damaged valve parts.

FIGURE 2–38.—He-O_2 and O_2 volume tanks.

How To Obtain Equipment

(20) All types of the helium-oxygen equipment, with the possible exception of the canister neoprene or Koroseal washers, can be obtained through the Navy supply system.

2.1.5 ACCESSORY DIVING EQUIPMENT

Sounding Line and Lead

(1) The sounding line and lead (fig. 2–41) are provided for determining the depth to which the diver must descend. It is important that this depth be determined with reasonable accuracy to anticipate the diving conditions, type of equipment, and personnel to be used, and to insure proper decompression. Accurate determination can be made as outlined in 1.4.7(13).

Descending Line

(2) The descending line (fig. 2–42) is used to guide the diver to the bottom and to lower tools and equipment. The line is made of 3-inch-circumference manila rope, and is cable laid to prevent twisting and to make identification by the diver easy. In rescue and salvage work, after the sunken vessel has been located, a line is usually attached to the wreck by the diver. In subsequent dives, the diver slides down the line to reach the desired point on the wreck. In diving operations requiring searching or observations, etc., the descending line is lowered directly to the bottom by shackling its end to the eye of a 100-pound weight. In strong tideways, should the 100-pound weight fail to remain on the bottom, additional weight can be added.

Distance Line

(3) A distance line (fig. 2–42) made of 15-thread cable-laid manila, 60 feet long, is attached to the descending line above the weight. This line is used by the diver in rotary searching and as a guide for relocating the descending line when he is ready to ascend.

Decompression Stages

(4) The diver's decompression stages (fig. 2–43) are used for putting one or two divers over the side and for bringing the divers to the surface in accordance with the decompression tables. The single-diver stage is 3 feet long and 18 inches wide; the two-diver stage is 5 by 4 feet. The stage platform is made of flat crossbars spaced about 1 inch apart to permit it to pass through the water with a minimum of resistance. The platform is mounted on two wooden skids for deck protection. Eyebolts of approximately 1⅜-inch inside diameter are welded to the middle of each end of the platform for attaching guy ropes for steadying the stage, suspending weights, or permitting the diver to brace himself. On the front of the single-stage platform and on the side frame of the two-diver stage is secured a guide through which the descending line is passed when lowering the stage to the diver. The bails of both stages are made in two sections to permit the stage to collapse for ready stowage. At the top of the stage is a 2½-inch-inside-diameter ring for securing the stage lines.

Stage Lines

(5) Stage lines are not furnished with the stage but should be made up on board to suit the particular needs of the vessel. The lines are of 3- or 4-inch manila rope with marks made 10 feet apart, corresponding to the decompression stops. As the decompression tables are prepared

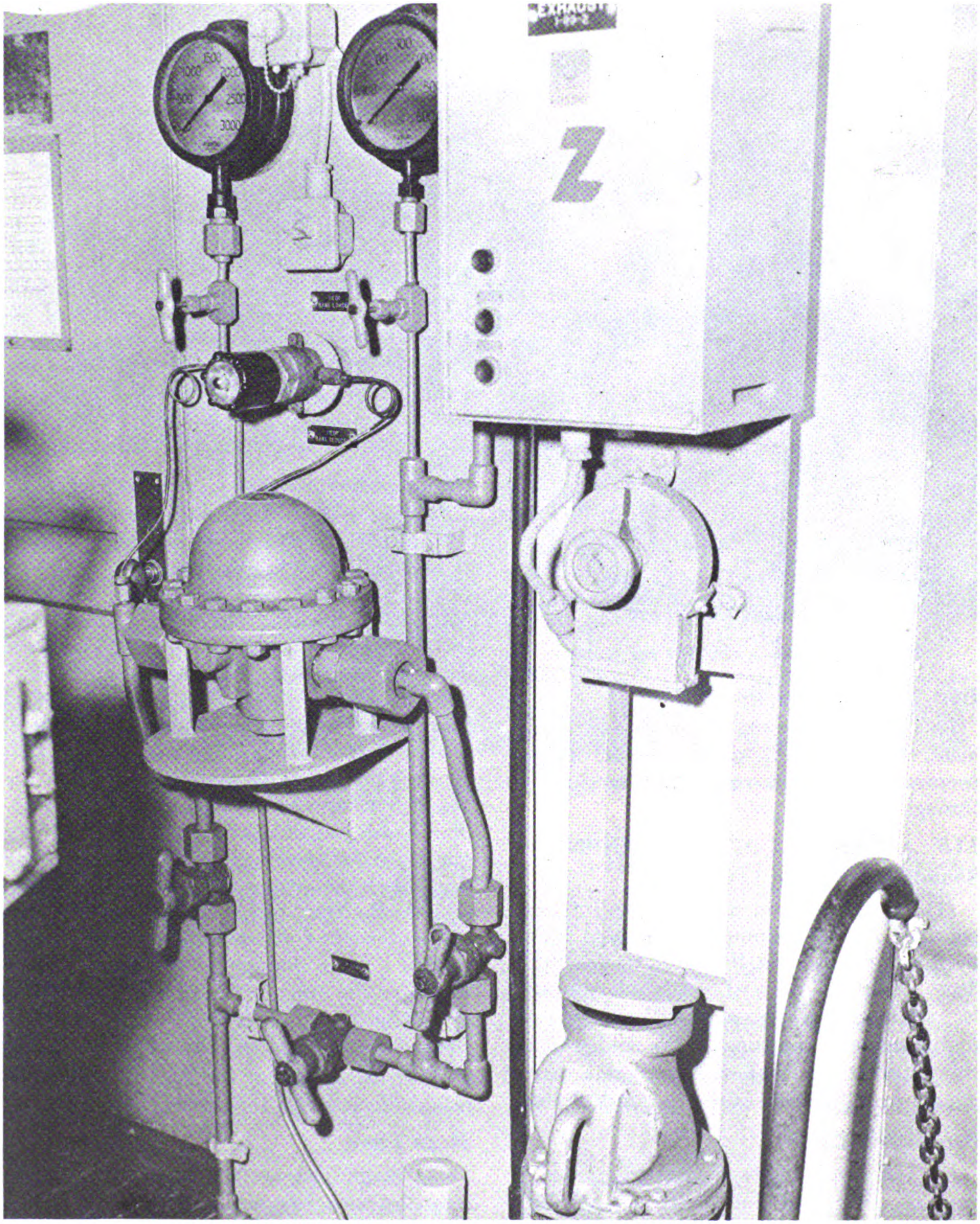

FIGURE 2–39.—He-O_2 bank piping and valve arrangement.

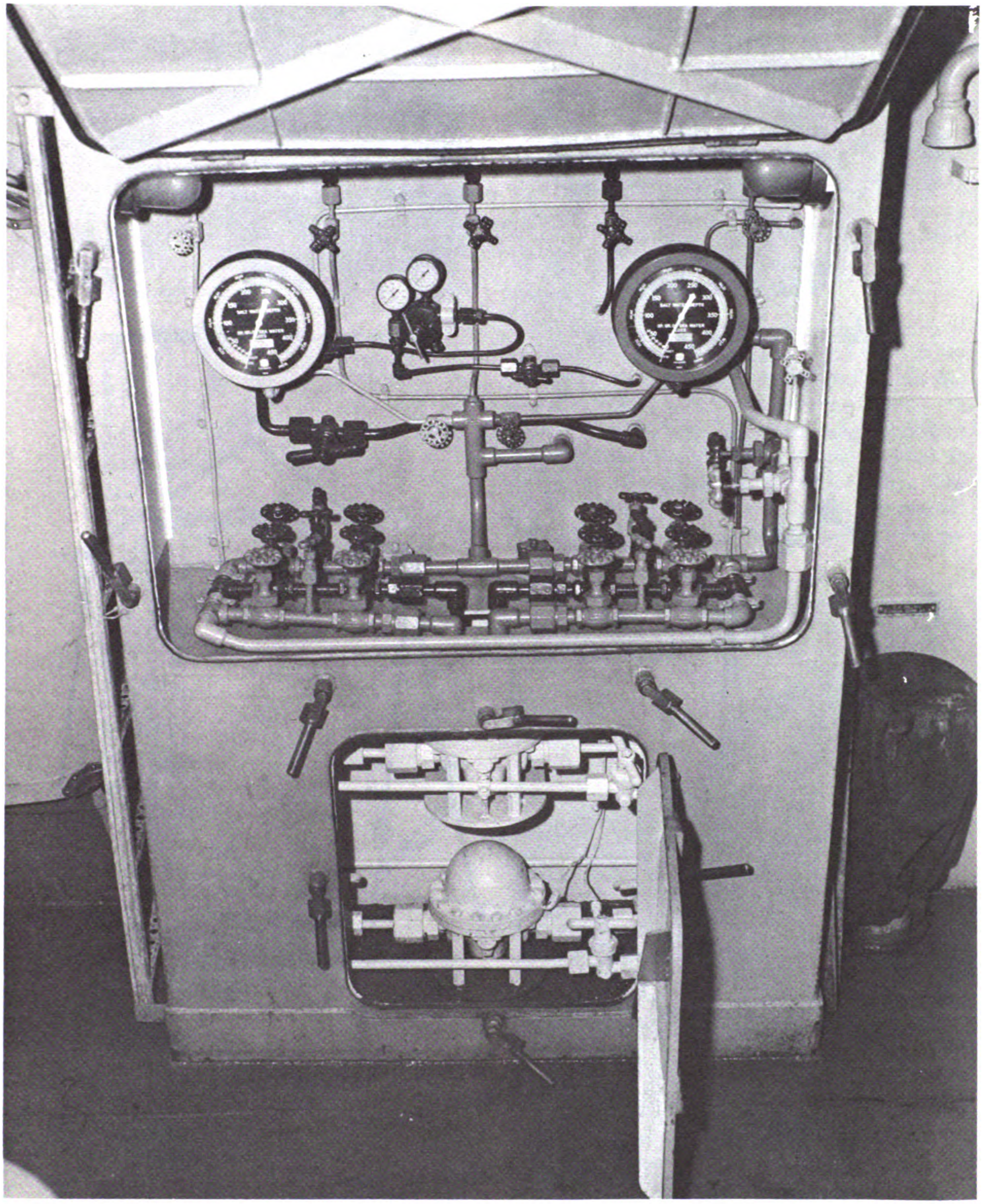

FIGURE 2-40.—Diving station control manifold.

FIGURE 2-41.—Sounding line and lead.

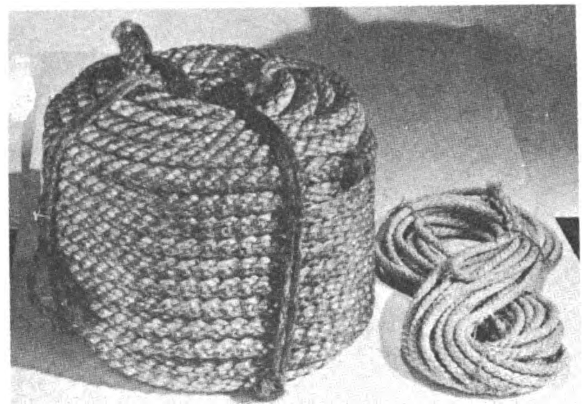

FIGURE 2-42.—Descending and distance lines.

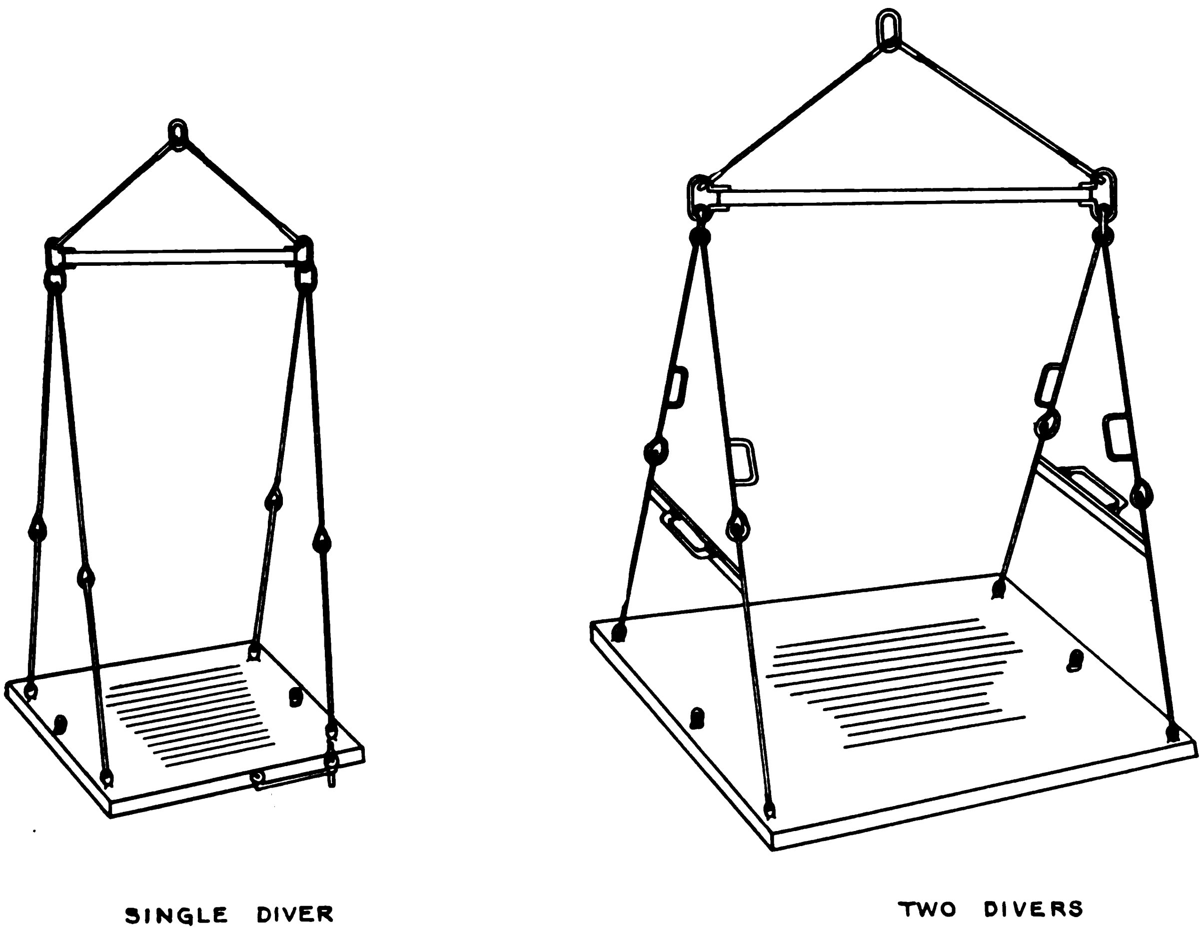

FIGURE 2-43.—Decompression stages.

on the basis of the entire body being below that required by the decompression stop, the depth of each decompression stop is measured from the surface of the water to the top of the diver's head. As individuals vary in height, it is necessary to use an average distance in determining the location of the first marker. The distance used is 16 feet from the deck of the platform.

Diving Ladder

(6) The diving ladder (fig. 2-44) is used for entering and leaving the water when diving over the side of a motor launch. The struts that give the correct inclination of the ladder when in use may be folded against the frame after removing the securing bolt to facilitate stowage. The latter is made of medium steel and is heavily galvanized.

Cast-Iron Weights

(7) Cast-iron weights are provided in two sizes: 50 and 100 pounds. The 50-pound weights are generally used with the decompression stage or as marker-buoy weights, and the 100-pound weights are descending-line weights.

Toolbag

(8) The toolbag (fig. 2-45) is used for carrying any tools that may be required by the diver for doing a job. Usually the toolbag, if not too heavily loaded, will be looped over the diver's right arm while he is on the ladder, just before entering the water. If it is heavily loaded, it should be sent down the descending line. The bag is made of heavy canvas and is perforated with grommets for easy drainage and for se-

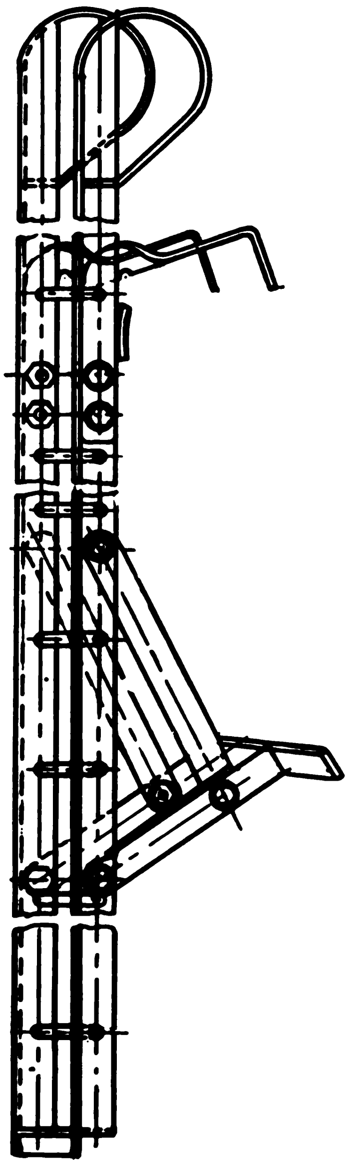

FIGURE 2-44.—Diving ladder.

FIGURE 2-45.—Toolbag.

curing tools. After use, the bag should be washed with clean water and allowed to dry thoroughly before stowing.

Lights

(9) One of the greatest handicaps experienced by divers is reduced vision under water which may range from zero to near normal, depending on the turbidity of the water. In many instances the diver working on a muddy bottom has to depend entirely on his sense of touch to accomplish a job. The value of underwater lights will depend on the water conditions. The extent of light penetration or diffusion of light under water depends principally on the amount of opaque matter suspended in the water, inasmuch as the opaque matter scatters the light, creating a haze. Increasing the power of the light increases the intensity of illumination but does not materially increase the radius of diffusion, nor does the use of reflectors to project the rays contribute materially to greater penetration. Reflectors are useful in protecting the diver's eyes from the glare of the light at its source.

(10) To provide light where it may be feasible, two underwater lights have been developed. The medium-pressure underwater light (fig. 2–46(*a*)) consists of the lamp with a rubber socket for making a watertight seal with a commercial 100-watt photoflood bulb (any commercial medium base bulb may be used) and 200 feet of cable. The light has been found satisfactory for use in moderate depths down to 150 feet. The second light (fig. 2–46(*b*)) consists of a 1,000-watt lamp, lampholder of seamless brass tubing, and a chromium-plated copper reflector fitted with a wire-mesh guard. This light is designed to withstand pressures equivalent to those at 500-foot depths.

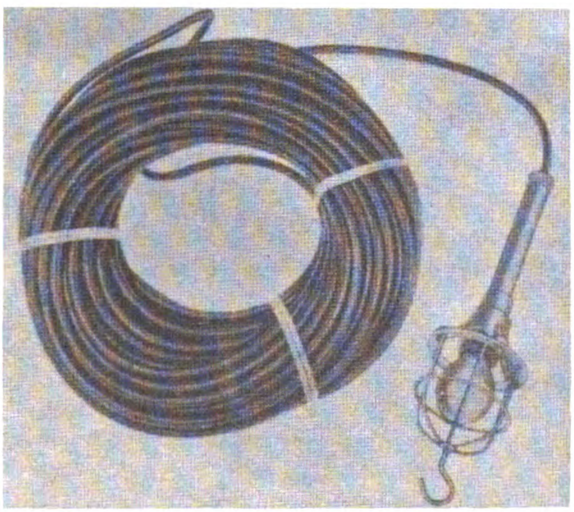

FIGURE 2–46(*a*).—Underwater light.

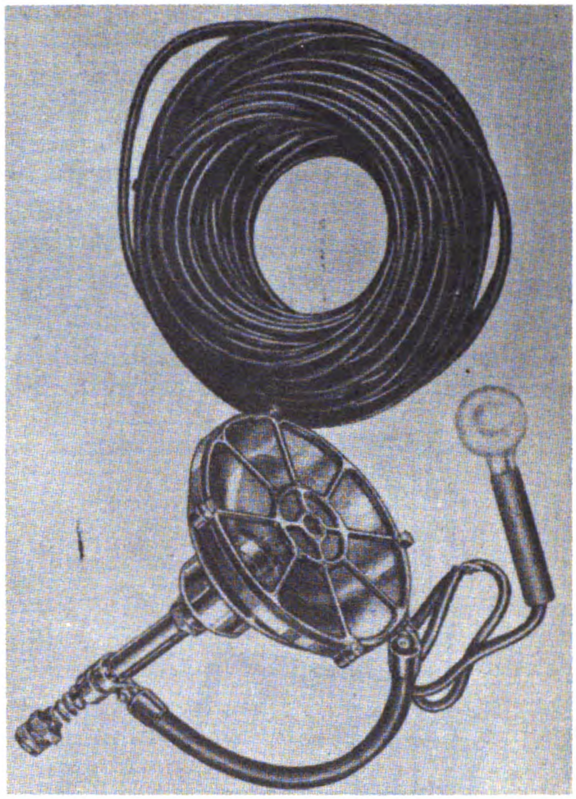

FIGURE 2–46(*b*).—Diver's lamp.

(11) All types of underwater lights must be submerged before being turned on, and the current must be turned off before hoisting the light from the water to prevent possible breakage from the resultant change in temperature.

Stopwatch

(12) The stopwatch is furnished primarily for timing the decompression stops.

Spare-Parts Box

(13) The spare-parts box (fig. 2–47(*a*)) is used for storing in one place small fittings, springs, and tools that are furnished with the diving outfit. The box is made of 22-gage sheet steel and is 15 inches long, 8 inches wide, and 9 inches deep. The box should be inspected regularly to guard against rusting.

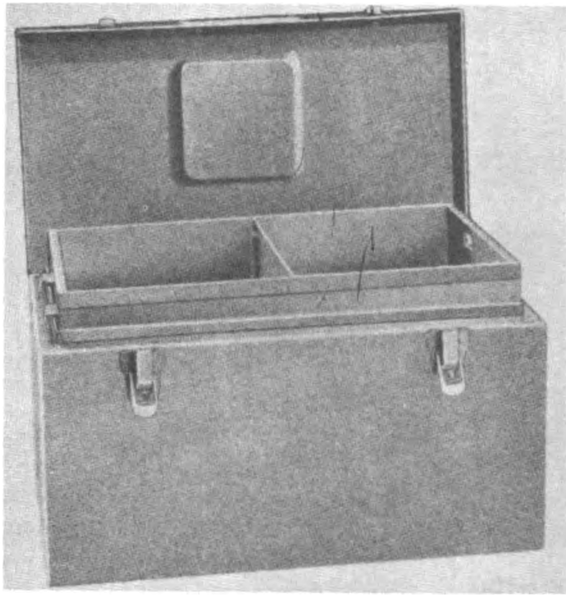

FIGURE 2-47(a).—Spare parts box.

Helmet and Outfit Chests

(14) Helmet and outfit chests (fig. 2-47(b)) are used for stowing the diving helmets and the various other parts of the diving outfit. Both chests are made of sheet metal and are 37 inches long, 17 inches wide, and 23 inches high. The chests should be checked periodically to guard against rusting.

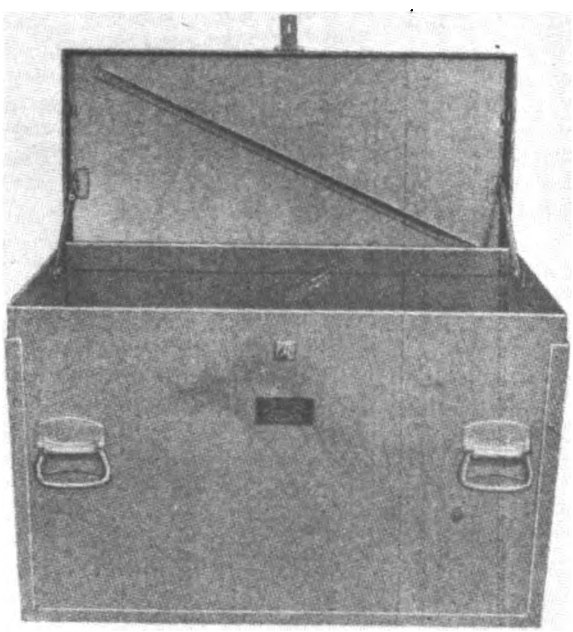

FIGURE 2-47(b).—Helmet and outfit chest.

Rubber Cement

(15) Rubber cement is furnished for patching the diving dress and for attaching the divers-tenders gloves or cuffs to the dress. As the cement contains a curing agent that will cause it to lose its adhesive properties within a short time if left exposed to air, it should be kept in a tightly sealed container when not in actual use. (See app. C for safety precautions governing the use of rubber cement.)

Dies and Taps

(16) Dies and taps are furnished for rethreading damaged bolts, nuts, couplings, and other diving fittings. There are two set of taps and dies: one for rethreading the helmet breastplate studs and wingnuts (½ inch, 12 threads); the other for rethreading air-hose fittings, reducers, and manifolds (1$\frac{1}{16}$ inch, 17 threads). The taps and dies should be given a protective coating of heavy oil when not in use.

Wrenches

(17) A wrench is furnished for the air-hose couplings, telephone couplings, and for securing the helmet breastplate nuts (fig. 2-48).

2.1.6 INSPECTIONS AND TESTS

(1) Upon receipt of diving outfits, in whole or in part, the gear shall be carefully inspected, tested, and made ready for immediate use in every detail. It will thereafter be maintained in the best possible state of readiness.

(2) All diving apparatus, except spare parts, shall be inspected once each week for cleanliness, conditions of stowage, etc. Helmet valves, faceplates, and fittings shall be examined; telephone batteries tested; diving dresses inspected for damage or dampness and repaired and aired, if necessary; dirty woolens washed and dried; oil separators cleaned, if necessary, and their filters washed in hot water and dried; diving knives and their cases, all tools and metal fittings cleaned and lightly oiled; diving shoes, belts, and other leather parts treated with neat's-foot oil as indicated; lengths of air hose that have been coupled together a long time shall be parted, the coupling threads lightly oiled, cleaned of grease or dirt; the interior of all

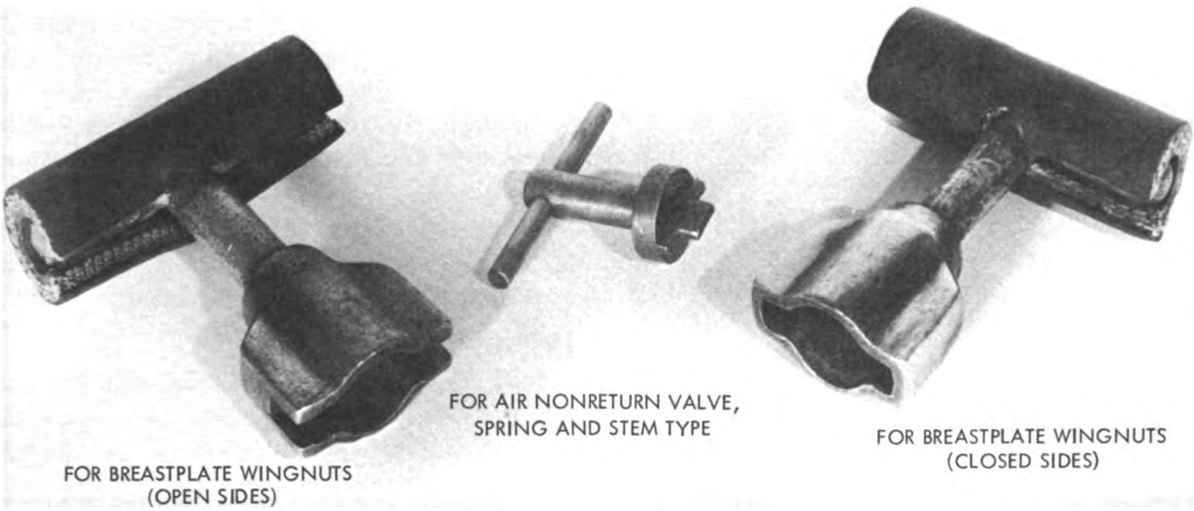

FIGURE 2-48.—Wrenches.

chests must be cleaned of any oil, grease, or dirt.

(3) All diving equipment on board ship shall be closely inspected once each month. Each outfit shall be inspected as to its completeness and satisfactory condition. Exhaust valves, air-control, and nonreturn valves of the diving helmet, and all valves of the diver's air-supply system shall be tested for satisfactory operation. Diving telephone systems shall be checked and tested.

(4) Weekly and monthly preventive maintenance checkoff lists should be provided for all diving and associated equipment to insure continuous maintenance. These lists should indicate the condition of equipment and the need for replacement.

SECTION 2.2 DIVING COMMUNICATIONS

2.2.1 METHODS OF COMMUNICATION

General

(1) Communication between the diver and his tender is of utmost importance to the safety of the diver and to the efficient accomplishment of the work being attempted. In addition, it is desirable to provide adequate communication between divers who are working together so that they may assist each other effectively. This subject is covered in detail in 1.4.7 (2) to (10) with regard to visual and mechanical methods. Electrical means in present use are listed below.

Electrical Communications

(2) In view of the limitations of hand signals, some form of electrical communication that permits the use of voice communication is necessary. By suitable equipment design, it is possible to provide dependable two-way amplified voice communication which will permit talking from the diver to the tender and will not require the person on either end to wear any sort of headband or microphone harness. To provide a convenient term to describe the amplified type of system as compared with the older telephone types, it is recommended that the terminology "divers' intercom" be used. To talk on this system would be to talk on the "intercom." Details of the use of the intercom are found in appendix C.

SECTION 2.3 DIVER'S AIR SUPPLY

2.3.1 AIR REQUIREMENTS

General

(1) The most important consideration in surface-supplied diving is that of providing to the diver an adequate supply of air suitable for him to breathe. For dives to shallow depths when an abundant supply of good air is readily available, there is very little concern about the actual amount used by the diver. However, in most instances inherent limitations of the diving installation or greater requirements of depth demand consideration of the adequacy of available air. This consideration must be based on various factors determined by the diver's air requirements at his maximum depth and maximum amount of work.

Helmet Ventilation

(2) Because 3 percent carbon dioxide at atmospheric pressure is about the maximum that can be tolerated without distress, it is essential that this equivalent partial-pressure percentage should not be exceeded in the helmet. Accordingly, the volume of air passing through the helmet of a deep-sea diving outfit must be sufficient to keep the concentration of carbon dioxide below the surface equivalent of 2 percent if possible and below a maximum of 3 percent. The relationships between a diver's carbon dioxide production, his breathing, and his helmet ventilation requirement have been previously discussed. Pertinent information is reviewed in this section.

(3) The diver's rate of production of carbon dioxide depends mainly on the amount of work he is doing. In terms of volumes measured at the surface, a diver will produce approximately 0.01 cubic foot of carbon dioxide per minute while at complete rest, 0.05 cubic foot while doing a moderate amount of work, and as much as 0.10 cubic foot during periods of heavy exertion, which is 10 times the amount at rest. To keep the concentration of carbon dioxide from exceeding 1 percent, the volume of air used to ventilate the diver's helmet must be 100 times the volume of carbon dioxide produced. If the volume of air is 50 times the carbon dioxide production, carbon dioxide concentration in the helmet will be 2 percent, and so on. For example, to keep the concentration below 2 percent effective during a moderate working dive of at least $0.05 \times 50 = 2.5$ cubic feet of ventilating air would be required each minute.

(4) Although the depth of dive does not change the number of cubic feet of air required for helmet ventilation, it must be understood that the volume of air needed is measured at the absolute pressure of the depth. Therefore a diver who requires 2 cubic feet of air per minute at the surface will also require 2 cubic feet at 99 feet (4 atmospheres absolute), but the actual volume in terms of free air at the surface will be $2 \times 4 = 8$ cubic feet (Boyle's law).

(5) A minimum air supply of 1.5 cubic feet per minute (measured at the absolute pressure of the diver's depth) would keep the surface equivalent of carbon dioxide in the helmet below 3 percent if the diver's carbon dioxide production were less than 0.045 cubic foot per minute. This means that 1.5 cubic feet per minute would only be adequate for light work, but that better ventilation is required for all practical purposes. Whenever possible, the volume of air supplied to a diver should be at least 4.5 cubic feet per minute at the absolute pressure to which the dive is made. This amount would be ample for all but brief periods of the most strenuous work. It is important to consider that any means of surface supply must provide a sufficient volume of air not only for the diver, but for a possible relief diver.

(6) To determine the volume of free air (as measured at the surface) required by a diver, the following formula may be used:

$$S=4.5\times N\times\frac{(D+33)}{33}$$

where

S=air supply in cubic feet of free air per minute

N=number of divers

D=depth in feet

For example, two divers working at a depth of 80 feet would require:

$$S=4.5\times 2\times\frac{(80+33)}{33}$$

where

$S=4.5\times 2\times 3.4$

S=30.6 cubic feet of free air per minute

Lightweight Mask Ventilation

(7) The flow of air required in the mask of a lightweight diving outfit must be at least equal to the rate of the diver's inspiration. This rate will normally be about three times his respiratory minute volume (1.3.4 (12) and (13)). In turn, his RMV will be about 25 times his carbon dioxide output. Therefore, normal breathing requires that the air supply be equal to about $3\times 25=75$ times the diver's carbon dioxide production. Less than that volume will cause discomfort to the diver. The lower limit of tolerance is about 50 times the carbon dioxide output. This is the same supply volume needed to maintain an effective concentration of 2 percent carbon dioxide in a helmet, showing that the lightweight outfit mask requires at least the same amount of air as the deep-sea helmet.

Overbottom Pressure Requirements

(8) It is considered advisable to maintain in the diver's air hose an air pressure of at least 1 atmosphere in excess of the absolute bottom pressure. The excess pressure is provided so that there will be immediately available additional pressure over absolute bottom pressure to compensate for any increase in bottom pressure should the diver fall, thereby possibly preventing a "squeeze." The amount of overbottom pressure to be maintained in the hose will depend on the available pressure at the air source, loss in the system before reaching the diver, whether or not the type of work is such that the possibility of falling exists, etc. A pressure in the hose of 100-psi overbottom is considered desirable for dives of more than 120 feet and at least 50 psi for dives of less than 120 feet, whenever capabilities of the air-supply system will permit.

2.3.2 SOURCES OF COMPRESSED AIR

(1) There are three general sources of compressed air:

(*a*) Internal combustion engine-driven air compressors.

(*b*) Air flasks.

(*c*) Shipboard air (ASR Divers' Air System).

Types of Air Compressors

(2) To meet the various diving requirements of the large number of activities having diving equipment and that are called on to undertake diving operations, two general types of air compressors are available: heavy duty and light weight. The type of compressor to be used will depend on the type of diving operations to be undertaken. For operations that require keeping a diver or divers in the water for extended periods, where the compressor will be subjected to rigorous use, or where the work is located in such a place that the diver cannot make a direct ascent to the surface, or for reasons of decompression, the heavy-duty compressor should be used. The lightweight air compressor is used for minor jobs, inspection, or searching, where ascent can be made directly to the surface without decompression, where the compressor is not subjected to continuous use, etc. While the heavy-duty compressor may be substituted for the lightweight compressor for minor diving jobs, the lightweight compressor should not be used where the working condition requires the use of a heavy-duty compressor. See appendix B for details of compressors.

Auxiliary Air Supply in Case of Compressor Failure

(3) To provide the greatest possible degree of safety, provisions should be made to furnish air to the divers from an auxiliary air supply should the compressor fail. The following standby arrangements should be made:

(*a*) Vessels having a shipboard supply of air should arrange suitable outlets with necessary valves and filters so that a line can be run to the manifold on the diver's air compressor during diving operations.

(*b*) Vessels that do not have a shipboard air supply should use a compressed air flask as a standby.

(4) With reference to the depth to which the compressor can furnish air, any information in the compressor manufacturers' catalogs that conflicts with the instructions in this manual should be disregarded if a deeper depth is indicated.

Operation With Submarine High-Pressure Air Flasks

(5) When diving operations are to be conducted from a vessel carrying submarine high-pressure air flasks or air flasks, a satisfactory and convenient air system can be achieved by connection of three or more air flasks. A typical air-flask installation is shown in figure 2-49. This arrangement consists essentially of four 8-cubic-foot, high-pressure air flasks, connected by copper tubing to a high-pressure strainer, then to a pressure-reducing valve, to a 1-cubic-foot-volume tank, and then to the diver's manifold. A high-pressure gage should be located on the high-pressure side of the reducing valve, and a low-pressure gage should be connected to the volume tank. A complete detailed description and bill of materials is contained in BUSHIPS Plan 19738-S4904-298223 Alt. 1.

(6) In diving operations using compressed air from submarine high-pressure air flasks or air flasks, at least one flask shall be open and left open during the time the helmet is being worn by the diver. The diver's air supply shall be taken from the volume tank, and the pressure of the air therein shall be prescribed by the diving officer.

(7) When diving operations are to be conducted from a small boat, insure that the air supply is sufficient for all dives planned and also for a relief diver in the event of an emergency. Also, not more than two divers shall be permitted to dive from the same boat. When the diver's air is supplied from submarine high-pressure air flasks, at least three or more flasks must be connected and ready for use; one flask

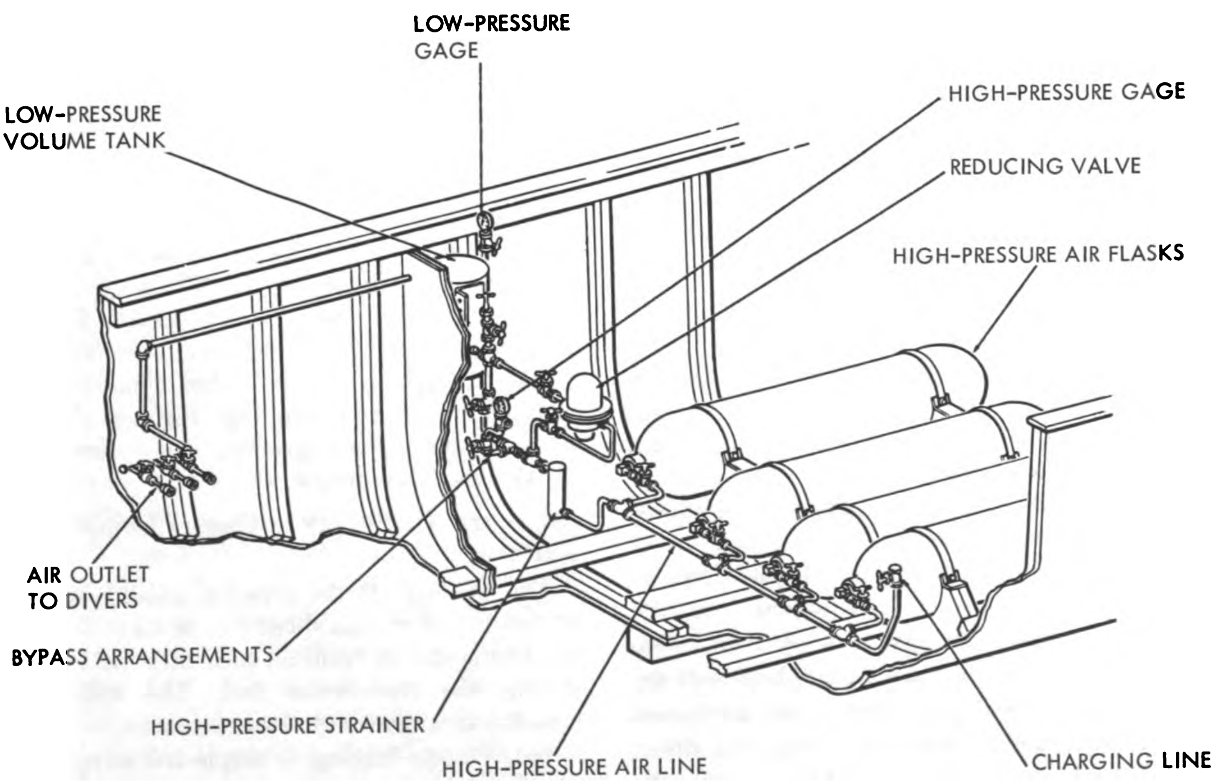

FIGURE 2-49.—Air-flask supply system.

shall be held in reserve. The pressure in the working flasks, as indicated on the high-pressure gage, shall not be permitted to fall below 220 psi in excess of the pressure used while the divers are working on the bottom. If the gage pressure in the working flasks (excluding the one held in reserve) approaches 220 psi, the divers shall be brought up. After they are clear of the bottom and safely on their way toward the surface, the reserve flask may be used. An exception to this rule will be permitted if there is available an additional independent air supply that can be connected immediately to the diving air manifold.

Duration of Supply From Air Flask

(8) The duration of air supply from the air flask may be calculated according to the following formula:

$$\frac{CN(A-(15+E+1))}{4.5\,D(E+1)}=\text{number of minutes on the bottom}$$

where

C=capacity of one air flask in cubic feet of free air
N=number of flasks
A=gage pressure in atmospheres of air in flask (psi divided by 14.7)
E=gage pressure in atmospheres to which dive is to be made (depth in feet divided by 33)
D=number of divers

(9) In this formula, the "1" in the numerator is one air-flask atmosphere which is allowed for charging the volume tank, air hose, and helmet. A and E are each added to 1 to convert them to absolute values. The "15" is the 15 atmospheres constituting the 220-psi pressure that has to be preserved in the flask as a minimum reserve. In the denominator, the "4.5" is the cubic feet of air required by each diver per minute measured at absolute pressure, and the "1" is the 1 atmosphere of pressure that must be added to the pressure at which the dive is made to obtain the absolute pressure. One air flask is held in reserve and should not be considered as available except in an emergency.

Example: Two divers are to descend to a depth of 165 feet. Determine the total time of the dive if air is furnished from four 8-cubic-foot air flasks charged to a pressure of 3,000 psi.

$C=8$
$A=204$
$E=\frac{165}{33}$ or 5
$D=2$
$N=3$ (the fourth flask held in reserve)

Calculation:

$$\frac{8\times3(205-(15+5+1))}{4.5\times2\times(5+1)}=81 \text{ minutes on the bottom}$$

(10) When calculating how long the air flask will last, it is important that the time for decompression be considered. In the above illustration, if it were decided to use the 70-minute table, it would require 2,786 cubic feet of free air to decompress two divers.

	Cubic feet
3 minutes to reach bottom (average depth of 83 feet)	63
50-foot stop for 8 minutes	91
40-foot stop for 17 minutes	169
30-foot stop for 19 minutes	163
20-foot stop for 51 minutes	369
10-foot stop for 86 minutes	505
Time between stops, 3 minutes at average depth of 83 feet	48
Required air per diver	1,393
Required air for 2 divers	2,786

This would exceed the volume of the reserve flask (assuming that it was entirely consumed) by $2{,}786-8\times205=1{,}146$ cubic feet which must be obtained from the other three cylinders. This in turn would reduce the time that the divers can stay on the bottom as follows:

The total quantity of free air in the three cylinders is

$$CN[(A+1)-(15+5+2)]=24\times183=4{,}392$$

The length of time the divers can stay on the bottom is equal to

$$\frac{(4{,}392-1{,}146)\times81}{4{,}392}=60 \text{ minutes}$$

This is the maximum time that two divers can stay at 165 feet and still have an adequate amount of air for decompression.

(11) To maintain the CO_2 content within safe limits, it may not be necessary to furnish 4.5 cubic feet per minute during decompression

(measured at the absolute pressure of the dive) as the diver's physical activity will be at a minimum. However, in computing the length of time that a flask will last, the 4.5-cubic-foot figure should be used. This inserts a safety factor in favor of the diver.

Low-Pressure Accumulators

(12) Air for diving can be furnished using high- and low-pressure accumulators. The air pressure in low-pressure accumulators is maintained constant by large capacity low-pressure, steam or electrically driven, automatically controlled air compressors. The capacity of these compressors is such that there is never a question of shortage of air supply. The maximum depth to which a diver or divers may descend will depend on the pressure of the air supply and the amount of air that is required to pass through the diver's helmet. When using this source of supply, determination of whether adequate ventilation exists is made by the diver's own feeling of well-being and by observing the accumulator air pressure.

High-Pressure Accumulators

(13) By high-pressure accumulators, reference is made to the air accumulators of the torpedo installation aboard vessels equipped with air-driven torpedoes. When connections are made to accumulators, diving operations should be conducted directly from or in the immediate vicinity of the vessel carrying the accumulators, thus obviating the necessity for use of long lengths of air hose. If the accumulators are of sufficient capacity, diving may be undertaken from those already fully charged, but if they are not of sufficient capacity to meet the requirements of depth and duration of the dive without recharging, then the compressor shall be operated as necessary.

Capacity of Air Compressor and Accumulators

(14) The capacity of the air compressor and the accumulators must be known and taken into consideration when calculating the air supply. For example, the capacity of a compressor is 15 cubic feet per hour at 2,500 psi, or 0.25 cubic foot per minute at 2,500 psi. As 2,500 psi would equal 2500/14.7 or 170 atmospheres (gage) or 171 atmospheres (absolute), 0.25 cubic foot per minute at 2,500 psi pressure would equal 171×0.25, or 42.75 cubic feet per minute at atmospheric pressure. Therefore, because a diver must have an air supply of 4.5 cubic feet per minute at a pressure equal to the absolute pressure at which the dive is made, a dive by one diver to, let us say, 274 feet, or 8.3 atmospheres, excess pressure (9.3 atmospheres absolute) would require 4.5×9.3, or 41.85 cubic feet of air per minute at atmospheric pressure. From this, it is evident that this power-driven compressor working at full capacity would just be able to furnish this supply of air. Under no circumstances, however, should divers be permitted to dive to the capacity limit of their air supply, whatever the source utilized may be.

(15) Also, sufficient air must be held in reserve to enable the dispatch of a relief diver. The capacity of the air accumulators aboard may be augmented by connecting them to the submarine high-pressure air flasks that have their stop valves open, and taking the air lead from this connection. When charging high-pressure accumulators, it must be remembered that the air is heated by the compressor's cylinders; hence, Navy Symbol 2190T or prime oil "D" should be used to prevent flashing in the cylinders, thus preventing CO and CO_2 production; or, if not available, castor oil may be used. For this and other reasons, as little oil as possible should be used in the cylinders. The air intakes of any compressors used for supplying diver's air must be located in atmosphere that is free from noxious or toxic fumes.

2.3.3 OPERATING METHODS AND PRECAUTIONS

Diving Operations From a Vessel

(1) When diving operations are to be conducted from a vessel, using the vessel itself as a diving platform, the necessary air connections should be made and precautions taken to insure a continuous and adequate quantity of air of desired purity. In the case of the submarine-rescue vessel, diving operations are conducted directly from the vessel, and a compressed-air system is made an integral part of the vessel. A typical air system consists of—

(*a*) Diver's air supply composed of two compressors capable of supplying approximately 150 cfm of air at a pressure of 400 psi.

(*b*) High-pressure air compressors capable of supplying air at 3,000 psi.

(*c*) High-pressure air banks containing air at approximately 3,000 psi.

(2) The operation of the air system is an important part of the diving, rescue, and salvage routine. Qualified personnel should stand a continuous watch by the air compressors and insure that desired temperature and pressure are maintained and reported to the officer in charge of diving operations. These should be maintained within specified limits except in emergencies. When diving, rescue, or salvage operations are in progress and air is being used for both diving and blowing purposes, it is necessary to safeguard the diver's air supply; therefore, orders shall be such that they will insure against opening or closing any air valve without the knowledge of those supervising the diving.

(3) It is customary when diving is in progress to have one or both 400-psi compressors running on their governors, though air in sufficient quantity can be supplied by one. The reason for two compressors running is that, should one compressor fail, the other is available immediately to take up the load. The governors are set so that the compressor pumps against a certain pressure. If one should stop, the other can be speeded up immediately, thereby maintaining the air in the volume tank at the desired pressure. Further, with both machines on the air-supply line, the load is divided and the safety factor of each compressor is increased. The air ends of the compressor should be cleaned each night after diving has ceased. The valves should be removed, cleaned with soapy water, wiped off with a castor-oiled rag, and wiped dry with a clean rag. The high-pressure air banks should be kept charged to their maximum capacity for emergency-diving air supply in event of failure of the air compressors. The banks are connected to the diver's air hose through a reducing valve that decreases the air pressure to the desired level.

(4) The diving air plants installed on the submarine-rescue vessels have 400-psi compressors that permit a low dewpoint to be reached and that provide a greater volume of air through expansion when the pressure is reduced to 300, 200, or 100 psi, as required. This system also has two aftercoolers. The complete circuit includes the volume tank, heaters, and coolers.

(5) Because the relative humidity at no time is sufficiently low to insure the delivery of air from the compressors at less than 100 percent humidity, the relative humidity of the atmospheric air is not a determining factor in regulating the dewpoint of the air supplied to the divers. The relative humidity of the atmospheric air is, however, a gage of the amount of moisture in the air that has to be extracted during the reconditioning process, and serves as a means of regulating the interval of blowing down the coolers. When the relative humidity is from 50 to 70 percent, the coolers should be blown every 15 or 20 minutes; when from 70 to 80 percent, every 15 minutes; and when from 80 to 100 percent, every 10 minutes.

(6) An explanation of the determination of the amount of water vapor to be removed from the air in the reconditioning process appears in 1.2.6 (1) to (8).

Precautions in Supplying Air

(7) The following is a summary of the safety precautions that should be taken to insure proper operation of the diver's air system.

1. Heavy-duty compressor:

(*a*) Assign personnel to maintain the compressor in first-class operating condition.

(*b*) Add the proper grade of oil and correct quantity to the engine and compressor.

(*c*) Add water and antifreeze, as necessary, to water-cooled engines and, in the case of air-cooled engines, keep the cooling fins free from foreign matter.

(*d*) Keep all filters, cleaners, and separators clean.

(*e*) Make certain that the engine exhaust fumes are not permitted to enter the compressor intake.

(*f*) Service the engine and compressor regularly in accordance with the manufacturers' instruction manuals.

(*g*) Insure that the engine and compressor are warmed up and running smoothly before a diver is put over the side. Report immediately to the officer in charge of diving operations any indication that the unit is not operating in a completely satisfactory manner.

(*h*) When unit is stored, remove every 30 days and operate. Prepare again for storage as if it had been used for some time.

2. Torpedo air flasks:

(*a*) Hold one flask in reserve.

(*b*) Maintain sufficient air for adequate decompression.

(*c*) Check valves, gages, fittings, separators, and reducers to insure satisfactory condition before diving is undertaken.

3. When diving is conducted from a vessel:

(*a*) Make necessary air connections to insure continuous air supply and to prevent air from being accidentally diverted or shut off.

(*b*) Insure availability of a standby air supply in the form of a second compressor or air flasks should primary air source fail.

4. Regardless of the type of air supply used, the following conditions are essential:

(*a*) Maintain air temperature that will not cause discomfort to the diver.

(*b*) Insure that air is free from noxious fumes and as pure as possible. (In utilizing air from high-pressure accumulators, the air in the cylinders of the compressors is greatly heated in charging the accumulators, and oil with a high flash point should be used—Navy Symbol 2190T if possible) (2.3.2 (15) and app. B).

(*c*) Provide the diver with a sufficient volume of air at a sufficient overbottom pressure (2.3.1(8)).

(*d*) Maintain reserve air supply in case of failure of the air supply.

SECTION 2.4 BOATS AND FLOATS

2.4.1 USE OF SMALL CRAFT FOR DIVING PURPOSES

(1) Although the diving equipment and diving personnel are generally assigned to tenders, repair ships, and salvage vessels, there are a great many diving operations where it is not feasible to dive directly from the deck of the vessel, because the work may be inaccessible to a large vessel. In these cases the practice is to convert a motor launch or other small craft for diving purposes. Small boats are generally used where the diving jobs are of relatively short duration and are performed at different points over a wide area. In cases where a diving job entails perhaps months of diving in a small area, such as in harbor-clearance work, it may be convenient to build a diving float.

Conversion of Small Craft for Diving Operations

(2) Many types of small craft are suitable for conversion to a diving boat. However, before any attempt is made to rig a boat for diving, it should meet the following basic requirements:

(*a*) Minimum overall length, 40 feet.

(*b*) Minimum beam, 10 feet.

(*c*) Freeboard, 3 to 5 feet.

(*d*) Engine in good condition and hull seaworthy.

With these basic characteristics, the boat can be rigged for diving operations with ample space for a diving platform for storage of equipment and for the diving crew.

(3) A 50-foot launch will be used to illustrate the method of conversion to a diving boat. Figures 2–50 and 2–51 show a typical layout of a converted 50-footer and several other types of boats. To convert the 50-footer for diving, it is necessary, first, to remove all thwarts to make enough space available for diving gear. A portable partial deck should be placed over the midship section to be used as a platform from which all diving operations are conducted. This deck should be flush with the gunwale so that the diver can step from the deck directly onto the ladder. The deck should be of sufficient size that there will be enough room for two divers (one diver, one standby diver) and the tenders, plus the equipment to put the divers into the water. The deck must have sufficient railings to protect the diver and other diving personnel from being thrown overboard in rough water. Only personnel who are assisting the diver or his tender should be on the deck during the time the diver is in the water. Sufficient personnel should be detailed to man the launch independent of the men required to handle the diving gear. Before permitting the diving launch to leave the shore or immediate vicinity of the ship, the following equipment should be placed aboard:

- Complete diving outfit
- Stadimeter
- Boat's diving anchor gear with extra anchor for bow and stern
- Jackknives
- Steel tape measure and 6-foot rule
- Boat's compass
- 10-foot probe made of ¼-inch pipe
- Hand flags for signaling
- Boat box
- Binoculars
- Long heaving line
- Several large shackles
- A coil of small stuff (marlins) for lashings
- A luff tackle
- Drinking water
- Diving logs
- Other special gear as necessary
- Bucket of soapy water if dress without gloves is used
- Blueprint or sketch of job
- Decompression tables

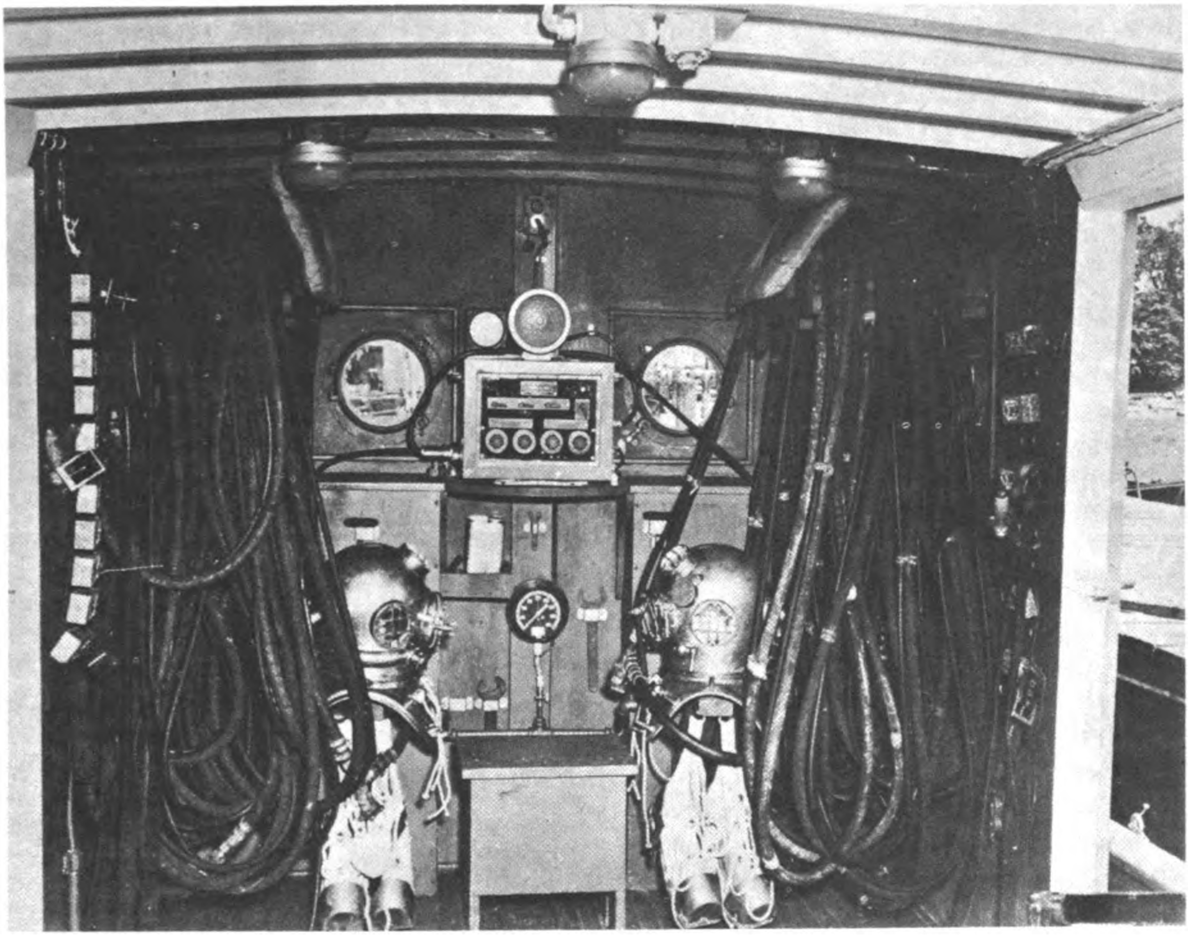

FIGURE 2-50.—Small craft diving arrangement.

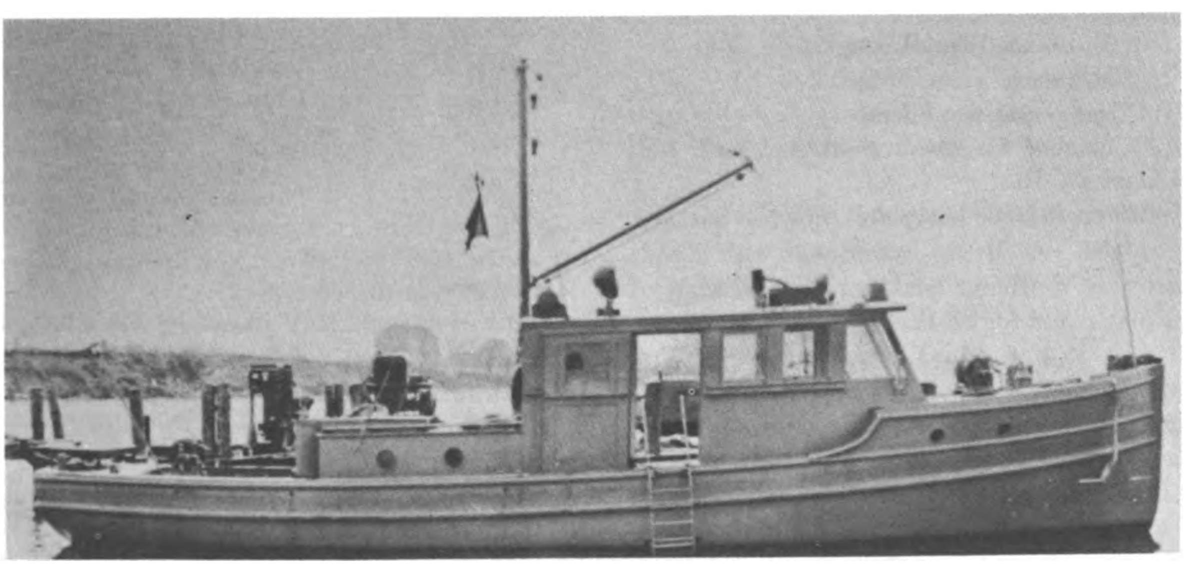

FIGURE 2-51.—Small craft fitted for diving.

First-aid equipment
Standard boat lifesaving gear

(4) Air compressors should be well secured and away from the diving operations. Unless it is absolutely essential, the compressor should be operated in the open. Should it be necessary to operate the compressor below deck, as in a confined area, the intake and exhaust must be outboard.

(5) If submarine high-pressure air flasks or high-pressure compressed air flasks are to be be used in lieu of a compressor, the necessary fittings and chocks should be fitted so that at least four flasks can be stowed in a readily accessible location. Figure 2–49 shows a sample air-flask installation. This arrangement consists of four 8-cubic-foot, high-pressure air flasks leading to a single ⅜-inch line; a ⅜ inch high-pressure strainer; an automatic reducing valve (3,000/100 psi), which can be bypassed in an emergency; a 1-cubic-foot volume tank; a 1¼-inch line leading to a three-outlet manifold. There is a gage on the high-pressure side of the reducing valve and a low-pressure gage on the volume tank. There is ⅜-inch copper tubing with the necessary valves for charging the air flasks.

(6) Should the motor launch be used for general duties, a rack can be made to hold the air flasks and auxiliary equipment, which can be lowered or hoisted into the boat for emergency diving jobs. To make the boat complete for diving, either two- or four-point moorings with an anchor winch in the bow of the boat can be used. The remainder of the diving equipment that is not being used can be stowed under the portable deck or in the chest in which the outfit was originally furnished.

Diving Floats

(7) Diving floats are useful for training divers and for undertaking diving operations in a closed harbor or basin where the water is reasonably calm. Floats used for such purposes may vary in size, but it is quite convenient to have in service one that is large enough to hold a number of divers with a number of sets of diving gear, and on which a large enough deckhouse could be built for storage of all necessary diving equipment.

SECTION 2.5 DIVING PROCEDURES

2.5.1 PLANNING AND ARRANGING OF DIVING OPERATIONS

Plan of Procedure

(1) When diving is to be undertaken, the commanding officer of the vessel shall be informed. When diving operations are to be conducted from a ship, the officer of the deck shall be notified. He shall further notify the commanding officer and engineering officer, and measures shall be taken to secure and tag any machinery or installations that might endanger the diver or diving personnel. Similar measures must be taken on the ships alongside before a diver is allowed in the water. Depending on the type of work, its location, depth, and climatic condition, a general plan of procedure should be decided on. The necessary officers, men, quantity and type of equipment, type of vessel or boat to be used, etc., to handle any emergency should be detailed and an effort made to conduct the operations with ease and efficiency. An officer qualified in diving is placed in charge of the divers and diving operations. If such an officer or warrant officer is not available, an officer familiar with the principles of diving and the problems encountered by the diver should be placed in charge. Regardless of the magnitude of the diving job, one person shall be placed in charge and assume responsibility for the divers and diving operations.

For additional details on planning and procedure, see 1.4.1.

Security of Moorings

(2) Upon arrival at the scene of diving operations, the local conditions should be observed to determine whether the vessel or motor launch can be moored and the diver put over the side. Sufficient gear should be carried by the vessel from which diving is to be undertaken to moor the vessel securely. The mooring gear should be given a careful inspection before mooring and, when divers are down, a watch should be placed to insure against any shifting of the moorings or veering of the vessel that would endanger the divers. Usually there is much less tide on the bottom than at the surface. Consequently, although the surface tide may seem strong, it may be advantageous to attempt diving, provided the surface tide is not such as to endanger the moorings. If the velocity of the current is over 1½ knots, the diver should wear additional weights. In sudden squalls, heavy seas, unusual tide, or any other condition that in the opinion of the commanding officer, jeopardizes the security of the mooring, the divers should be brought up and diving discontinued until more favorable weather conditions prevail.

Preliminary Planning of Operations

(3) The success of diving operations will be considerably enhanced by preliminary planning of operations, including the laying out of various phases of the work and the assignment of definite tasks to each diver or group of divers. In general, it is better to arrange the diving task so that the number of divers submerged is kept to a minimum. It should be remembered that the greater the number of divers submerged, the greater the possibility of entanglement of the lines involved, and that for continuous diving the number would be multiplied by the lines of the divers decompressing in the water. The number of divers that can safely be submerged simultaneously will depend on the depth of water, the nature of the bottom, the ship's facilities for handling divers over each side and the practicability of this procedure under attendant conditions, the freedom of the job from debris, and the conditions of the weather and sea. Divers can be used singly, in pairs, or in groups of three or more. It is generally preferable to work divers singly or in pairs. It is sometimes advisable to use divers in relays where one diver acts as another diver's tender, the first diver being tended topside.

(4) With the foregoing as essential requisites, contributions to the satisfactory operation of underwater work are made by application of the following rules:

(*a*) Make inspection dives to ascertain the extent of the work to be done and to determine the method of attacking the problem.

(*b*) On the basis of the initial inspection dives, consider the method of accomplishing the job, the type of equipment and personnel. Exercise care in evaluating the information obtained during an observation dive because the opportunity for observing conditions below the surface is limited. In addition, insure that the plan decided on is flexible enough so that it can be modified to take advantage of information obtained on subsequent dives and on the basis of how the work is progressing.

(*c*) Prepare and assign tasks and give the divers instructions well in advance. This will enable the diver to think over the task with the result that he may offer suggestions or ask questions that may assist in completing the job.

(*d*) A diver may unintentionally overestimate his ability to accomplish underwater work. Insure that suggestions are thoroughly considered and judiciously weighed by those in charge.

(*e*) Insure that each diver of a group, in addition to his own specific instructions, is given a general idea of what tasks the other divers of the group are to perform.

(*f*) Insure that final instructions are given to each diver and to the group by one person only.

(*g*) If the diver forgets part of his instructions, he must immediately ask advice from the diving supervisor. Therefore, insure that the diving supervisor is immediately available during diving operations.

(*h*) When a diver is on the bottom, it is inadvisable to alter the diver's prearranged task. It is better to instruct and send down a new diver to replace him.

(*i*) Work night and day, while weather permits, provided sufficient divers are available.

(*j*) In planning the work of divers, make arrangements that preclude any necessity for their stay on the bottom in excess of the optimum time of exposure relative to decompression and exposure.

2.5.2 THE AIR DIVE

Responsibility of Officer in Charge

(1) The officer or diver in charge shall see that the diver is properly dressed, the air hose and all air connections properly made, the air system, including compressor and secondary air system, are in satisfactory operating condition, communications tested, soundings taken, and all gear properly arranged on deck or in the diving launch before the diver begins his descent. The officer or diver in charge is responsible for the condition of the diving gear, and shall make sure that all equipment is in good working order before the diver is dressed.

Dressing Procedure

(2) As shown in figure 2–52, the diver first puts on the woolen or thermal shirt, drawers, and socks. The amount of underwear worn will depend on individual preference and climatic conditions. Next, he gets into the dress with the help of the tenders. The legs of the diving dress

FIGURE 2–52.—Dressing procedure (1).

should be snugly laced. Care should be taken, however, not to draw the lacings so tight that circulation of the blood in the legs is impaired (figs. 2–53 and 2–54).

(3) If cuffs are used instead of the gloves, the tender spreads each cuff by inserting his first and second fingers on each hand, while the diver, taking care to keep his fingers straight, forces his hand through the cuff. Rubbing soapsuds on the inside of the cuffs or dipping the cuffs and diver's hands in fresh soapy water facilitates this operation. If rubber wristbands are required, they are put on over the edges of the cuff. However, the effect of cold water, with the restriction of the circulation of the blood caused by the rubber wristbands, often results in a loss of the sensation of feeling in the hands so that there is danger of damage or injury to the hands when using tools. Accordingly, for work in cold water, a diver should be dressed in a suit fitted with gloves. When using gloves, also use leather wrist straps. Wrist straps are placed at a comfortable position on the diver's wrist. Wrist-strap buckles should be turned inward.

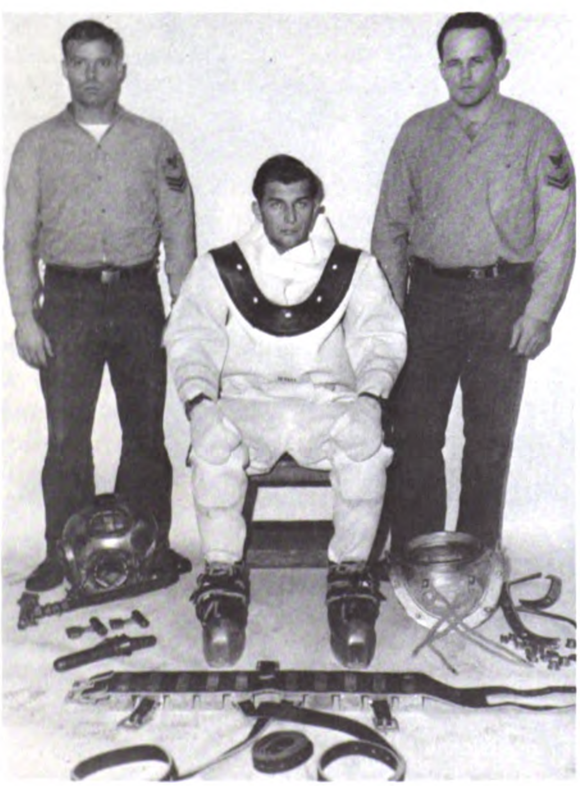

FIGURE 2–53.—Dressing procedure (2).

FIGURE 2–54.—Dressing procedure (3).

(4) Next, the canvas overalls, if used, are put on. Then the diver sits on the dressing stool, and the tenders place the weighted diving shoes on his feet and secure them with lacings and buckled straps. Lanyards should be well secured around the ankles and the straps pulled tight and buckled. Buckles should be outward.

(5) The helmet cushion is put on, followed by the breastplate (fig. 2–55). Care should be exercised to prevent the rubber collar from being torn when it is pulled up and placed over the projecting studs. The bib is drawn well up, and

the rubber collar is placed over the front of the breastplate, working it over the remaining studs in succession toward the back studs, alternately pulling up on the bib. Two tenders, one on each side of the diver, are best for this operation. The diver may, by elevating his arms, assist in getting the holes in the collar over the shoulder studs. Four copper washers are now placed on the studs where the breastplate straps join. The four removable breastplate straps are placed over the studs. The wingnuts are then run onto the studs; those on each side of the strap joints are screwed tight first, and those at the joints last.

(6) The weighted belt (fig. 2–56) is fastened on, making the leather shoulder straps cross in front of the diver's breastplate and over his shoulders outside of the top breastplate stud. In back, the shoulder straps again cross before being buckled. The diver then stands and the jockstrap is brought between his legs and, with all the slack taken up, buckled firmly in front.

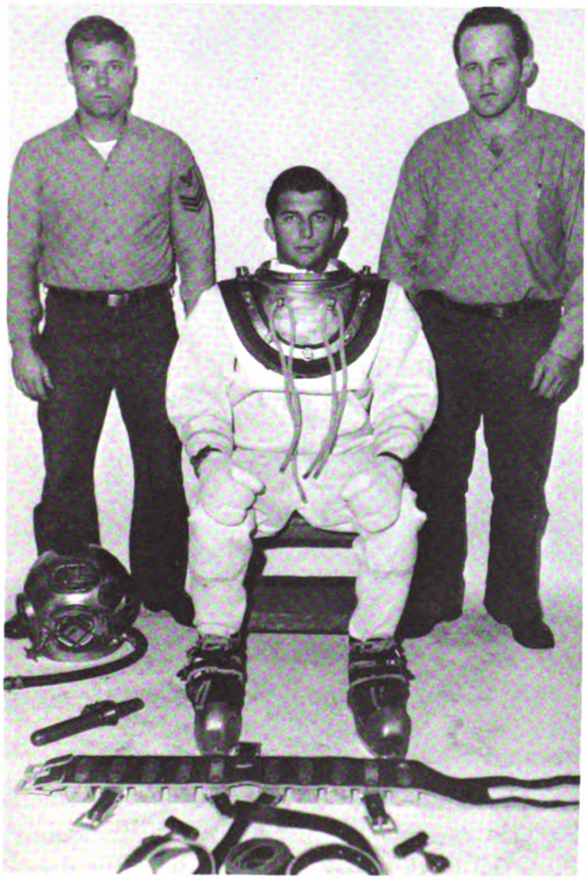

FIGURE 2–55.—Dressing procedure (4).

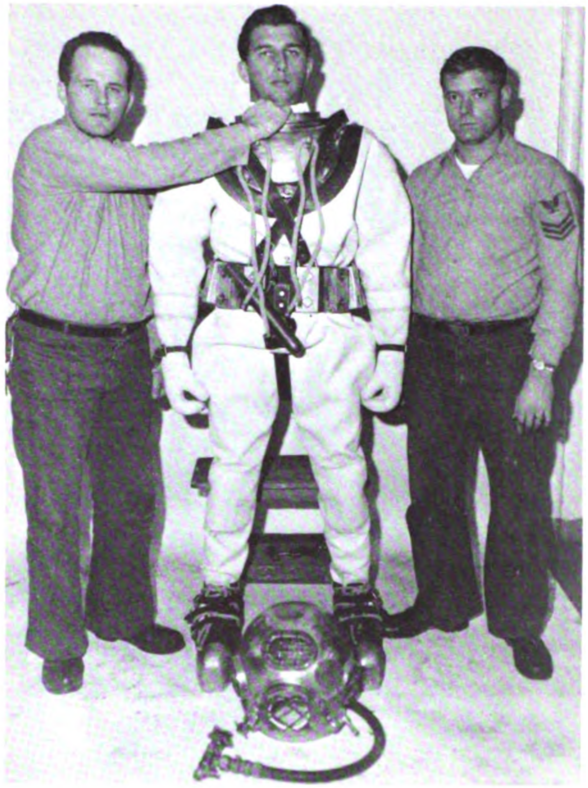

FIGURE 2–56.—Dressing procedure (5).

(7) Prior to the time the diver is dressed, the helmet should be examined, the valves and intercommunication system tested, the proper decompression tables determined for the depth and anticipated time on bottom, and the necessary lengths of hose coupled, care being taken that a washer is in place in each female coupling. One end of the 50-foot length of air hose should be attached to the inlet of the air-control valve and a 3-foot length of hose should be connected between the control valve and the nonreturn valve on the air-hose gooseneck. The lifeline is secured to the gooseneck on the back of the helmet. The air-supply system should be checked thoroughly. If a compressor is to be used, it should have been previously started and warmed up. Air should then be blown through the hose and helmet to clear the system of any dust or dirt. To reduce the possibility of fouling, the first 50 feet of hose and lifeline are married, and canvas then is sewed on. The remainder of the hose and lifeline should be seized at approximately 4- to 6-foot intervals.

(8) The helmet is then attached onto the breastplate (figs. 2–57 and 2–58). The ball lever of the safety lock is turned down into its recess and is locked in place by the safety latch and the split cotter pin. The combination amplifier and lifeline cable and air hose are brought up under the right and left arms, respectively. The combination amplifier and lifeline cable is secured to the right breastplate eyelet, and the hose to the left eyelet. The cable and hose are secured to the eyelet with signal halyard by taking two round turns and tying a square knot. The air-control valve is then attached to the bastard stud on the breastplate. The intercom is also tested by the diver.

(9) The tender insures that the diver is properly dressed, and particular care is exercised in insuring that the safety lock is secured. The diver then adjusts his exhaust valve and checks his air supply. The tender then closes the faceplate and locks it securely. The diver then steps onto the stage, placing his feet in the center and to the outside, grasping the iron bails with his hands. The knees should be bent slightly while riding the stage. The diver is hoisted clear of the ship's side, and is then ready to begin his descent.

FIGURE 2–57.—Dressing procedure (6).

FIGURE 2–58.—Dressing procedure (7).

(10) When the lightweight diving equipment is to be used, the diver is dressed in much the same manner as that described for the deep-sea diving equipment. Care should be taken to insure watertightness at the back opening and where the mask comes in contact with the dress face gasket.

Swimming on Surface

(11) If surface swimming is required for the diver to reach his descending line, the following procedure should be followed. When the diver enters the water, he adjusts his exhaust valve and control valve so that the faceplate is slightly out of the water when he is floating in a vertical position. When the diver is ready to begin swimming, he faces the direction in which he wishes to travel and pushes himself free of the ladder or stage. The leg motion used is a circular movement that is similar to pedaling a bicycle. At the same time the arms are used in a dog paddle to help propel the body forward. When the diver begins to move, the tender pays out enough slack in the air hose and lifeline so that the diver can make headway easily. If the diver has a tendency to fall over frontward when swimming, arching his back and leaning back in the suit will be found helpful. It should be remembered that the swimmer is in a vertical position and that his direction of travel is in the direction he faces.

Starting the Descent

(12) The diver remains on the stage or ladder until he is satisfied that the dress is tight, and air valves and telephones are properly adjusted and in working order. After reporting this by signal, he steps off and is hauled by the tenders to the descending line that is usually made fast at the point where the stage is put over. The diver locks his legs around the descending line and holds onto it, while he adjusts his air supply before he starts the descent. Figure 2–59 shows the diver making an adjustment of the air-regulating exhaust valve.

FIGURE 2–59.—Diver on descending line.

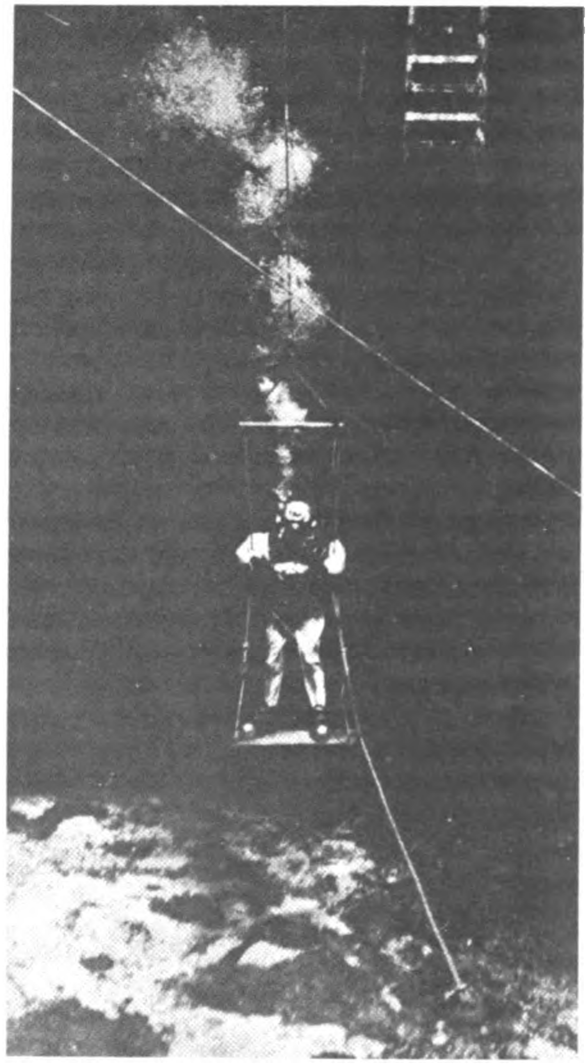

FIGURE 2–60.—Diver on stage.

(13) A second method of descending is by means of a decompression stage (as shown in fig. 2–60). The diver stands on the middle of the stage and supports himself by bracing his feet against the side and holding on to the stage

bails. The stage is then hoisted over the side and the descending line is passed through the shackle on the side of the stage. The diver is lowered until the helmet is awash. At this point the descent is halted until the diver adjusts the flow of air. After the proper signal is given the diver is lowered at a steady rate, allowing sufficient time for the diver to equalize the pressure. When the stage has reached the bottom, the diver steps off the stage from the same side he entered it. This will prevent the diver's line from becoming fouled with the stage.

Rate of Descent

(14) The rate of descent should not exceed 75 feet per minute, allowing for the diver's ability to equalize the pressure and "pop his ears," and for checking the descent whenever necessary. The factors limiting the rapidity with which a diver can descend are possibility of a squeeze, inability to equalize the air pressure on both sides of the eardrum, pains in the sinus passages, the tendency toward dizziness, the effect of currents, the necessity of approaching an unknown bottom cautiously, and other variable factors.

Pain in Ears and Sinuses

(15) Pain in the ears during descent is a warning that must not be neglected, as rupture of the eardrums is threatened. Proper action is for the diver to stop his descent and yawn, swallow, or press his nose against the wall of the helmet to block the nostrils and make a strong effort at expiration. Ascending 3 or 4 feet usually provides relief, and the descent then may be continued. If the dive is to be made in deep water and the diver has trouble with his ears in getting down to 30 feet, it is advisable to bring him to the surface and not let him dive that day. Pain in the sinuses is usually caused by head colds, and the only remedy is to prohibit the diver from diving until his cold clears up.

Regulating Air During Descent

(16) As the diver descends, care must be taken that air is supplied to him in the correct volume and at the correct pressure for his depth. Insufficient air supply during descent may force the diver to stop because of a squeeze. As the diver descends, air is forced out through the air-regulating exhaust valve by the pressure of the water, so that the dress presses closely to the legs, arms, and body up to the breastplate. The experienced diver adjusts the air supply so that he breathes easily and comfortably without endangering his stability.

Descending in Tideway

(17) When descending or ascending in a tideway, the diver should keep his back to the tide so that he will be forced against the descending line and not away from it. It is not difficult for him to maintain this position if he determines which way the tide tends to swing him and pushes the descending line over to one side or the other so as to check the swing.

Procedure Upon Reaching Bottom

(18) Upon reaching the bottom, the diver holds onto the descending line and adjusts his buoyancy to such a degree that the helmet merely lifts the weight off his shoulders. He should ventilate and should spend adequate time at the descending line to permit his body to adjust itself at the new pressure level.

Air-Supply Adjustment

(19) As the diver descends, it is necessary to adjust the flow of air continually to compensate for the increasing water pressure. Upon reaching the bottom, the diver should remain at the descending line long enough to regulate the flow of air to insure proper dress inflation and become adjusted to the new pressure level. Ordinarily, the dress will be properly inflated when the helmet and breastplate are just lifted from the shoulders and yet the negative buoyancy is not overcome. Next, it should be determined whether there is proper helmet ventilation. While the diver is standing at rest, he should feel physically comfortable and normal. Should there be rapid breathing, panting for breath, unnatural perspiring, undue sensation of warmth or dizziness, unclear eyesight, or should the helmet windows become cloudy, there is bound to be an accumulation of CO_2 in the helmet and the remedy is "more air." This can be accomplished by increasing the rate of circulation through the helmet. Proper inflation and ventilation can usually be obtained by opening the helmet air-regulating exhaust valve 2½ or

3 turns and then regulating the airflow with the air-control valve. The best practice is to adjust the exhaust valve at the same time as the control valve, i.e., increase air supply, increase exhaust; reduce air supply, reduce exhaust.

(20) There are many occasions where proper control of the air supply can be used advantageously to lessen muscular exertion and assist in completing the job. It is frequently desirable to alter inflation or deflation for short periods of time to accomplish specific tasks without readjusting the regulating escape or control valves. To cause a rapid deflation, the exhaust opening is increased by pushing the escape valve chin button outward. If a rapid inflation is required, the chin button should be grasped by the lips shutting off the exhaust. For a further regulation of airflow, the "spitcock" may be used.

Determining Direction

(21) Before leaving the descending line, the diver should note the lead of the hose and lifeline cable to insure that they have not fouled the descending line. To determine the direction, the diver should also note the bearing of the brightest light (diffusion of sunrays) and the direction of the current. By remembering the direction of the work with reference to the direction of the sun while on the surface, it is easy to proceed in the desired direction. If, for instance, before starting the descent, the sun shone on the left helmet window, the greatest amount of light should still shine in the left window of the helmet when on the bottom if the diver's position is the same as when on the surface in relation to the sun. If there is no light, the diver may depend on the direction of the current for guidance. The slightest general movement of the water can usually be detected by an experienced diver. However, the current does not always flow in the same direction on the bottom as on the surface and, consequently, if the diver should start off in the wrong direction, the tender should warn the diver.

(22) The most satisfactory method of determining the direction of travel is by tender-diver communications, either by intercommunication system or prearranged hand signals; so many pulls means to go to the right, so many means go to the left. A warning or signal to indicate directions means that the diver should first face the direction from which the lifeline and air hose are tending, and then obey the instructions (1.4.7(9)).

Movement on the Bottom

(23) When leaving the descending line, the diver should proceed slowly and cautiously to conserve his strength. It is advisable for the diver to carry one turn of air hose and telephone cable on his arm to prevent his being thrown off balance by sudden pulls from the surface. The immediate surroundings should be examined and a report made of any wreckage or obstructions encountered. As a general rule, it is advisable to pass over, not under, obstructions. In this connection, in passing any obstruction the diver should keep in mind the side on which he passes to avoid fouling on the way back.

(24) Movement is relatively easy in slack water, but as the tide or current increases, it becomes progressively difficult to advance. This difficulty may be lessened by advancing in a stooping or crawling position, which reduces the body area exposed to the sweep of the current. The crawling position is the easier one for navigation underwater. However, it should be remembered that every time the diver assumes a new position, consideration must be given to the regulation of the inflation of the dress.

Working on Rocky Bottom

(25) When working on a rocky bottom, the diver should guard against tripping and catching of legs or arms in crevices. If the rocks are sharp, as coral usually is, it is advisable to wear gloves. Particular attention should be paid to preventing the air hose and lifeline from catching on the rocks, and the tender should be cautioned about keeping the slack well in hand. If the lines become fouled, the diver should gather up the lines and retrace his steps by following the lead of the air hose and lifeline. In almost all cases, the diver will be able to clear his own lines without requesting the assistance of the standby diver.

Working on Muddy Bottom

(26) When working on a muddy bottom, the diver should remember to keep all movement

to a minimum to avoid stirring up the silt and reducing whatever visibility there may be. In addition, the diver should provide more buoyancy by keeping plenty of air in the dress. Sinking deeply into the mud indicates that there is an excess of negative buoyancy. While this condition can be corrected by increasing the inflation of the diving dress, the diver's movements in wiggling out of the mud should be as gradual as possible to eliminate the possibility of "blowing up" after breaking loose.

(27) Mud, quicksand, and such substances should not be regarded with fear. They are a cross between land and water; although their density is not sufficient to support the diver, it is great enough to offer more resistance to sinking than water. Divers have been known to work under many feet of mud and silt for relatively long periods without undue discomfort. The hazard involved in diving in muddy water is the inability to see such objects as pilings, stone walls, debris, cans, and bottles, that may cause the diver physical harm. One of the primary reasons for using deep-sea diving equipment in water where visibility is very limited is the physical protection offered by this type of equipment.

Searching for Lost Objects

(28) When searching for lost articles, the diver should explore thoroughly and as expeditiously as possible the whole of the ground within the sweep of the distance line. To accomplish this, the diver takes up the distance line, holding it taut, and starting from some point, sweeps around in a circle. After returning to the starting point, which must be judged by some object on the bottom, the direction of the tide, a line stretched along the bottom for the purpose, or signal from topside, the diver moves out along the distance line and makes a fresh circle in the opposite direction, thus avoiding the twisting of his air hose and lifeline around the descending line. It is generally more advantageous to crawl on the bottom when searching, though in exceptionally clear water, a better field of vision may be obtained by walking.

(29) When a diver has explored the whole of the ground in this way without finding the object sought, he may be fairly certain that it is not within the reach of the distance line; hence the next step would be to have the ship or the diving launch moved so that a new area may be searched. Before the ship or the diving launch is moved, the diver is brought up and the position is marked by a buoy so that a systematic search can be made. When a number of buoys have been thus planted over a considerable area, the unimportant ones may be removed by the surface crew. The important ones marking the boundary of the explored area should remain until the search is completed. The diver may be unable to make a complete circle if there is much tide or current. In that case, it is necessary to work back and forth across the tide as far as possible, each time moving out a little farther along the distance line until he reaches the end, and then to have the position of the diving boat shifted.

(30) Still another method of searching is to plant two large buoys a considerable distance apart. A surface line of adequate size manila is stretched between the two buoys. The diving launch with diver on the bottom is then ferried along, the surface line being taken over the bow and stern rollers of the launch, and the boat being given headway by pulling on the line or stopped by holding onto it, according to signal from the diver. The advantage of this method is that the speed of the boat is always under exact control.

(31) On finding the object sought, the diver should, if possible, fasten the distance line to it, after which he may signal for a line and have it hauled up or he may surface and make a report, as circumstances require. An object once found can always be relocated by means of the distance line tied to it.

Working About Moorings

(32) When working about moorings, a diver should not dip under chains, etc., unless it is absolutely required by the dive. As old moorings are often covered with sharp barnacles, gloves should be worn to protect the hands. A diver should not descend on a chain or wire if it is possible to do otherwise; and neither should a chain, wire, line, or weight be veered, lifted, or moved until the diver is clear of them.

Working With Several Lines

(33) When a diver is required to work with several lines, it is a good plan to have each of them of a different size or material, or marked by using colored rags or turns of small stuff, so that he may know their individual purpose. He should never cut a line until he has made certain of the purpose for which it is being used. Because a new line when under water shrinks and usually takes several new turns, it should first be lowered in the water by means of a weight and allowed to remain a considerable time before it is sent to the diver. Otherwise, if lowered alongside another line, it is sure to become fouled. For underwater work, cable-laid line is the safest and most useful.

Recovering an Anchor

(34) In recovering an anchor, the line of the watching buoy should be hauled up and down, and the descending line weight dropped close alongside it. The diver can then go down his descending line, keeping the buoy line in hand as he descends to prevent his descending line from fouling the buoy line.

(35) If a wire hawser must be shackled to an anchor, the task may be accomplished in the following manner: Prepare the wire by fitting a large shackle to the eye and by stopping another shackle with its crown against the wire a short distance above the eye. The pins of both shackles should be fitted with lanyards to prevent their loss under water. Shackle the wire to the descending line or to the anchor buoy rope (if watching) by the upper shackle, which will act as a traveler, leaving the end of the wire free for the diver to handle. When the diver has found the anchor, he should signal for the wire which should be carefully lowered to him; extreme caution should be exercised to prevent the wire from being dropped on the diver or too much being paid out, because large bights on the bottom render it difficult to find the end and may foul the diver. After shackling on, the diver should come up before any attempt is made to weigh the anchor. If the anchor is any distance from the descending line, or the buoy is not watching, the diver should bend his descending line on or get another line bent on so that the lifting wire may come down exactly where it is needed. The same applies for raising other heavy weights, such as guns or torpedo tubes, from a wreck.

Working on Ship's Bottom

(36) The amount of work that can be accomplished on ships' bottoms by divers depends largely upon the nature of the work and the degree of stable accessibility that can be maintained by the rigging of lines, ladders, and stages. Two or more Jacob's ladders lashed together side by side and weighted at the lower ends form a convenient arrangement for divers to work over the side of a vessel. If the ladder is hung from the ends of spars secured on deck and projected about 2 feet clear of the ship's side, it can be hauled under the bottom by hogging lines; the divers, then, will have room to work, will be able to move around freely, and, being on the inboard side of the ladder, will be protected from falling. For working beneath the bilge keels of large vessels where the bottom is usually flat, a good plan is to lace a net between two Jacob's ladders. The two ladders are separated by spars lashed in place to stretch the net, and the whole is passed under the keel by the aid of hogging and tricing lines. The diver can then lie back in the net and work on the bottom above him with comparative ease. When a diver is working under a ship, all lines must be carefully tended.

(37) Another quick and easy method of rigging a stage for the use of divers working on a ship's bottom is as follows: Two long spars, 20 to 25 feet long and about 4 feet apart, are connected to each other by two long lines; the bights are clove hitched around the end of each spar, the upper ends form the tricing lines, and the lower ends form the hogging lines. The tricing lines take the weight of the stage, and the hogging lines hold it down and bind it into the ship's side. A third spar about 16 feet long is hung to the lower of the two long spars by a slung weight, to keep it in a horizontal position about 3 feet below the lower long spar, sufficient weight being hung to the stage to overcome its buoyancy. To prevent the stage from being bound too close to the ship's side, crosses made from any rough pieces of wood about 3½ feet long can be used. One of these crosses is secured at each end of the upper spar. A small cleat nailed on the spar prevents the crosses from

slipping inward, and the clove hitches of the stage lines prevent them from slipping outward. The stage, suitable for two divers, can be raised or lowered bodily, the diver at each end giving his own signals. When fleeting the stage. the divers should come to the surface.

(38) In planning for emergency repairs to the hulls of vessels, the following items should be on hand: collision mats, patent leak stoppers, mattresses, canvas, swabs, cotton-waste calking, wooden wedges, mild steel plating for small holes, hook bolts, rubber gaskets, ample supply of planking for large holes, wire cable, bungs, wooden plugs for closing valve openings, and wire brushes and prickers for use in cleaning valve gratings.

Clearing or Removing Valves

(39) Valves, as a rule, can be easily cleared from the outside by means of a wire brush and a pricker to clear the holes. If barnacles have gathered inside the perforated covering, the grating must be taken off to destroy them. The position of the grating should be marked before removal to facilitate its replacement. If, after the securing plate has been taken off, a valve has been removed, the hole plugged up, and the plug cut off flush with the ship's side, the outside should be covered with wood and lined with a suitable material such as sheet rubber or canvas to prevent any leakage inboard. If the valve is to be kept out only a short time, this covering need be only temporarily fastened, as the pressure of the water on the outside will keep it in place.

Clearing Propellers

(40) Propellers usually get fouled by line or wire hawsers, and at times are very difficult to clear. A stage should be rigged near the fouled part (an iron grating will answer the purpose) to enable the diver to work in comfort.

(41) First, the fouling should be thoroughly examined to see if it is possible to clear an end; if so, and if the turns are jammed, line ends or tackles from the surface must be rigged and installed to break them out. Back turns can be taken or the propeller turned by the jacking engine to insure that the lead of the tackle is at its best. Particular care must be taken to see that the diver and stage are out of the way when the propeller is being turned. The engineering officer and engineering officer of the watch must always be informed whenever a diver is working about the propellers.

(42) If no end can be exposed, then the hawser must be cut. Rope hawsers can be cut with a knife, hacksaw, or carpenter's chisel. There are several practical methods of cutting fouled wire cables, such as by burning with underwater gas or electric torches, or by cutting the cable with a sharp chisel or saw.

Working Around Corners

(43) When a diver is required to drag a long length of lifeline and air hose, or when it is necessary to work around several corners, an additional diver or divers are of assistance in tending the lines at intervening locations on the bottom or on deck. Thus, if the intercommunication system should fail, the diver can send signals to one of the divers tending his lines, who, in turn, would transmit them to the surface by intercommunication system or signal over the first diver's lines, using his own lines only for signals affecting himself. However, it should be borne in mind that the greater the number of divers submerged simultaneously, the greater the possibility of fouled lines. Whether the benefits of this procedure justify the acceptance of the greater possibility of fouling depends on the emergency or circumstances involved. This procedure will be at the discretion of the officer or diver in charge.

Guarding Against Falls

(44) Whenever a diver is working clear of the bottom, as on a rocky ledge, ship's bottom, or deck of a vessel, caution should be exercised to prevent falls. The significance of a fall is that there is a sudden increase in external pressure without a corresponding increase in internal pressure, which may result in a serious accident called "squeeze." Falls in shallow depths are more serious than falls in deeper depths. In falling from the surface to a depth of 33 feet, the pressure on the body is doubled and the volume is reduced by one-half, while in a fall from 165 feet to 198 feet, the pressure is only increased by one-sixth and the volume is reduced one-seventh.

(45) The diver should always have something substantial to hold on to. However, it is dangerous to hold on to something overhead and climb around in this manner as the air in the dress may escape from the cuffs or leaks in

a torn glove, in which case the diver may become so heavy that a fall is precipitated. Similarly, a diver should never go under the keel of a ship and come up on the other side, for if he fell it would be extremely difficult for the tender to assist in checking the fall.

(46) Should a fall occur, the descent can be checked by the tender if the lines have been held sufficiently taut, or by the diver's increasing the flow of air through the control valve and gripping the regulating escape-valve chin button between the lips to reduce the exhaust, thereby gaining additional buoyancy by inflating the dress. However, when inflating the dress, it is important that the other extreme (overinflation) does not cause a "blowup." A blowup can be prevented by reducing the flow of air through the control valve and providing full exhaust by pressing the escape-valve chin button.

Fouled Diver

(47) When a diver discovers that he has become fouled, he should immediately stop and think over the situation. It should be remembered that there was a way into the situation, and there is similarly a way out. He should remain calm and attempt to extricate himself by slow methodical efforts. Topside should be notified, if possible, by "voice" or hand signal so that the standby diver can be sent to provide assistance if required. The diver should then take the distance line, with the lifeline and air hose, and retrace his steps until the point is reached where the lines have become fouled. The necessary steps should then be taken to untangle the lines. After several attempts have been made without success, assistance should be requested and a relief diver dispatched.

(48) The relief diver should follow down the fouled diver's air hose and lifeline to find the tangle. However, if, after the tangle is found, he is unable to release the fouled diver, arrangements should be made to substitute a new air hose and lifeline. To accomplish this, the relief diver fastens the new lifeline around the fouled diver's waist. Next, the relief diver closes the fouled diver's air-regulating exhaust valve and air-control valve, then uncouples the nearest free coupling or the air-control valve and couples on the new hose. If an air-control valve is not used, it is important that the hose coupling to be broken is at or below the level of the fouled diver's feet. If the air supply to the new hose is turned on slightly to form a small stream of bubbles, the water will not enter the fouled diver's air system.

Loss of Distance Line

(49) If the distance line is lost, the diver should feel carefully for it on the bottom within his reach. But if, after this simple maneuver, he does not find the distance line, he should inform the surface of the loss and that he is coming up. The attendant should guide the diver over to the descending line, and as the diver is hauled toward the surface, it is highly probable that the diver will discover the distance line. As soon as the distance line is located, the surface tenders are advised by means of the signal "lower." The diver descends and, with the distance line again in his possession, returns to work.

Sending Down Tools

(50) Definite arrangements should be made by topside personnel to insure that the diver receives the necessary tools to do a job with the minimum physical strain. Tools that the diver is to carry down should be fitted with lanyards and slipped over the diver 's right arm or placed in the diver's toolbag. When tools are not to be carried down by the diver but are to be sent to the diver, a special descending line of 2½- or 3-inch line should be secured to the point where the material is to be used. The line should be given an angle of lead that will cause anything sliding down to land so that the diver can easily locate it and guide it into place. When a power tool is to be sent down, it should precede the diver, and should be attached by a piece of six-thread manila to a sliding shackle on the descending line, and lowered to the bottom by the tool's air hose. An electric torch and ground wire or a gas torch and igniter can be sent down in the same manner as the power tool, except the ground wire or torch hose is used as the lowering line. For all other objects, use 15- to 21-thread manila for a lowering line, led from well forward to prevent turns, attached by an eye splice to the sliding shackle on the descending line; the small objects are, in turn, attached by a short piece of marline to the shackle.

Safety Precautions

(51) To work efficiently and safely under water, a diver should keep in mind the following general rules and facts:

(*a*) The air-regulating exhaust valve adjustment should be set at the desired number of turns open prior to starting the dive.

(*b*) The diver should adjust his air so that he is able to breathe comfortably.

(*c*) To quickly release the suit pressure when the diver wants to stoop or crawl on the bottom, the helmet air-regulating exhaust valve stem known as the chin button can be used effectively without changing the air-control valve and the air-regulating exhaust valve adjustment.

(*d*) The combined discharge of air-regulating exhaust valve and spitcock will not exceed the flow of air that will pass a half-open control valve; hence movement of the control valve wheel must be very small.

(*e*) The air-control valve should never be completely closed, except during rupture or replacement of the air hose.

(*f*) The helmet spitcock offers a secondary method of relieving excess pressure in the helmet.

(*g*) The safety air nonreturn valve and the air-regulating exhaust valve will seat themselves if the diver's air supply is impaired, but the spitcock, if open, must be closed immediately by hand.

(*h*) The diver is never in danger from a leaking dress provided he remains in an upright position. Divers have descended to a depth of 274 feet with the helmet only.

(*i*) Air trapped in the diving helmet will last from 6 to 9 minutes for breathing purposes after diving air is cut off, thus providing ample time for emergency measures to be executed. The diver should try to remain calm and rest to conserve his supply of air.

(*j*) If the diver should crack his faceplate, he should keep it downward and increase his air supply to prevent leakage.

(*k*) The diver should never become frightened or excited; slow, methodical efforts are always best in an emergency. Inexperienced divers have been known actually to exhaust themselves worrying over very simple circumstances. Such a state of mind is both needless and useless. The diver should never make the foolish mistake of running away from his air supply and consequently from safety; i.e., he should not become panic stricken and make violent exertions to escape from a tangle when the proper course is to go slowly and deliberately. When in trouble, he should slow down his exertions and, if relief is not immediate, rest awhile. No matter how serious the situation appears, the diver should remember that there was a way into his predicament, hence there is also a way out of it, and if he cannot solve the problem himself, then the standby diver will.

(*l*) A diver must have confidence, first in himself, and second in those who are tending him.

(*m*) If the diver is fouled and cannot extricate himself, the standby diver who is sent down must be prepared to replace both air hose and lifeline, a procedure that may be safely executed on the bottom.

Preparation for Ascent

(52) After the diver has completed the task or has received instructions from the surface to come up, the necessary preparations for ascent should be made immediately. If a special line has been used for sending down tools, the diver should request that a line be sent down so that the toolbag or other tools can be sent to the surface prior to starting the ascent. If no special line has been used, the diver should return to the descending line via the distance line, and a line should be sent down for attaching the tools. If the descending line cannot be located and the tools are too heavy to be thrown over the diver's arm, a line should be secured to the lifeline which the diver then pulls down. The toolbag is made fast and the tender is signaled to haul the bag up.

Beginning the Ascent

(53) When everything on the surface is ready, the tender advises the diver to stand by to "come up." The diver, after making certain that everything is clear and there is nothing to interfere with the ascent, places one leg around the descending line, as in the manner of descending, and lightens his weight as necessary by inflating the dress. In doing this, the diver should be extremely careful not to overinflate the dress, which may result in a "blowup." While the diver can assist the tender by lightening himself, the

diver shall be lifted off the bottom by the tender. In this connection, the decompression tables of section 1.5 are based on the requirement that the diver is brought to the surface at a specified rate which can be more accurately controlled by the tender than the diver.

1. Everything being ready, topside is then notified, "Ready to come up." When ready, the tender will notify the diver, "Coming up. Report when you leave bottom," and then will lift the diver toward the surface. The diver reports when he leaves the bottom. If the diver feels his dress becoming too buoyant and he is ascending too rapidly, he may check his rise by clamping his legs on the descending line and adjusting the inflation of his dress by regulating the air-regulating escape valve. If the dress is not fitted with gloves, reduction in inflation of his dress can be rapidly accomplished by the diver's raising his arm which will permit excess air to escape at the cuff.

2. During the time the diver is preparing to come to the surface or just prior to it, the decompression stage is secured to the descending line by a shackle fitted to the stage and is lowered to the first decompression stop. When the diver is warned by surface tenders that he is nearing the stage, he should keep a sharp watch for the stage. As soon as the diver finds it, he should climb upon it and seat himself. When this is done, the topside should be notified, "On the stage," so that the beginning of the proper decompression at this first stop can be started and timed.

3. During the time spent on the first and subsequent stops, the diver should see that his lines are clear of the descending line and stage. In case of fouled lines, he should report the fact immediately to the tenders and they will aid him to unfoul the lines as much as possible. Similarly, when the fouling of lines is detected by the tenders, the diver should be appraised of the fact. When the lines are clear, the diver should notify the tenders, and they should confirm the fact by repeating back the message, before starting to hoist the stage.

4. When the diver is ascending and is on the stage, he should pay close attention to messages from the surface and in all cases endeavor to answer clearly and distinctly. When word is received from the tenders that the stage is to be hoisted, the diver should assure himself that his hold on the stage is secure before returning the OK signal to the surface. Prior to leaving his last stop, the diver should stand firmly on the stage before signaling that he is ready to be brought to the surface.

Ascent From Dive Made From Motor Launch

(54) The foregoing instructions for ascents cover procedure in diving from vessels such as submarine-rescue and salvage vessels, which are properly fitted with hoisting and other diving facilities including a recompression chamber. The instructions are equally applicable to ascents from dives made from motor launches except that the stage must be hauled up by hand instead of a powered winch.

Decompression

(55) The diver is brought to the surface in stages to prevent decompression sickness or, as it is more commonly called, bends, diver's paralysis, or caisson disease. The tables for decompression, and the causes and treatment of decompression sickness have been previously discussed, as have the two methods of decompression: standard decompression and surface decompression.

(56) The standard method of bringing the diver to the surface with stops at various depths for various times in stages specified by the prescribed decompression tables shall be followed in all cases, except in emergencies or conditions of tide or weather that, in the opinion of the officer or diver in charge, warrant surface decompression. When the stage arrives at the surface after regular decompression, it is lifted and swung clear of the gunwale, lowered lightly to the deck, and the diver assisted from the stage. As soon as the diver is seated, the faceplate is opened and the air-supply valve closed. If a recompression chamber is available, the diver can be undressed at once. If a recompression chamber is not available, and there is any question about the diver's condition, an attempt should be made to transfer him to the closest available recompression chamber. If this is impossible, prepare for water-recompression treatment as a last resort.

(57) In surface decompression, the stage is lowered to the deck as before. The diver's hel-

met, belt, and shoes are removed as quickly as possible and he is escorted to the recompression chamber by the attendant, who enters the chamber with him and removes his suit as the pressure is raised to that corresponding to the first decompression stop. Not more than 3½ minutes should elapse from the time that the stage leaves the water until the diver is inside the recompression chamber and is again being subjected to pressure (1.5.5.(2)).

(58) Regardless of method of decompression, the diver is to remain in the vicinity of the recompression chamber or facilities for underwater decompression for the required length of time (1.4.7 (26) and (27)).

Stowage of Gear

(59) When diving operations are completed, all gear should be cleaned and then stowed in a dry, cool compartment, and kept in good repair and in readiness for immediate use. All chests of diving apparatus should, when sufficient space is available, be kept habitually stowed under cover, away from steampipes and excessive heat. When it is necessary to keep them in the open and exposed to the weather, suitable canvas covers should be used to protect the outfit.

2.5.3 THE HELIUM-OXYGEN DIVE

Introduction

(1) During the years of experimentation and operation with the use of helium-oxygen mixtures, a great many tests have been made. In general, the result of this work indicated that—

(*a*) The breathing of helium when mixed with the proper amount of oxygen is harmless.

(*b*) The rate of absorption of helium by the body tissues and its elimination from these tissues is more rapid than that of nitrogen.

(*c*) Body tissues saturated with helium will contain less gas than will body tissues saturated with nitrogen. For instance, the watery tissues, such as blood or lean muscle, will hold about 1½ times more nitrogen than helium. In addition, the proportions of gas held by the different types of body tissues vary with nitrogen and helium. Thus, tissues that are high in fat content, such as fat, bone marrow, and spinal-cord substance, will absorb more than five times as much nitrogen as will the watery tissues. For helium, the proportion of gas held by these respective tissues is only about 1.7 to 1. By simple calculation, the fatty tissues would, therefore, hold about 4½ times more nitrogen than helium.

(*d*) As the rate of absorption for helium is more rapid than that of nitrogen, some tissues will take up more helium during a short exposure at a given depth. However, on decompression, the rate of elimination of helium from these tissues will also be more rapid than that of nitrogen. Cavitation (the formation of bubbles) can occur during decompression following both air and helium dives. Because helium is eliminated rapidly owing to its lower solubility, more molecules of the gas become available earlier to form bubbles. Hence, the first decompression stop must be deeper in helium dives than in air dives. Accordingly, it must be emphasized that a diver can contract bends when using helium-oxygen mixtures as well as with normal air and that decompression in accordance with the tables is essential.

(*e*) Oxygen and helium must be mixed in proper proportions to suit the depth of the particular dive involved. The oxygen and helium may be obtained in separate cylinders and mixed as required. Oxygen concentration must be kept within the safe limits of 1.6 atmospheres absolute pressure of pure oxygen. During decompression, the diver can be shifted to pure oxygen at 50 or 40 feet, as indicated by the partial-pressure table involved, to hasten helium elimination from his body.

(*f*) Divers are more mentally alert when breathing helium-oxygen mixtures under pressure than when breathing air. The sense of depth commonly experienced when breathing air is greatly reduced. Also, divers can work considerably harder and for longer periods because better ventilation of the diver's lungs takes place with the lighter helium atmosphere.

(*g*) The advantages of using surface-supplied helium-oxygen mixtures in lieu of air are applicable mainly to diving to depths in excess of 150 feet. Consequently, this equipment is furnished only to submarine-rescue vessels.

Removal of Carbon Dioxide

(2) Because of the characteristics of helium and the fact that the helium-oxygen mixtures have to be furnished in bottles, it was necessary to provide special equipment and to modify the standard deep-sea diving equipment. Early

experiments with helium-oxygen mixtures were carried out using open-circuit helmets in the same manner as for air diving, but experience soon showed that expenditures of the gas mixture far exceeded the requirements of the diver. Development of the present equipment followed.

(3) Consideration of the gas laws previously discussed shows the cause of this difficulty. It is necessary to maintain a circulation of at least 3 cubic feet per minute through the helmet of a working diver to keep the CO_2 content at a safe low level. This ventilation, being simply a mechanical sweeping-out process, must be maintained regardless of ambient pressure, and must be measured at the depth of the diver. At 363 feet (12 atmospheres absolute), the necessary supply will be increased to $12 \times 3 = 36$ cfm, if measured at the surface. An average flask of helium-oxygen mixture (charged to 1,800 psi) contains only about 173 cubic feet of usable gas when account is taken of the last 200- to 300-psi pressure which is necessarily wasted. Therefore the gas is being used at a rate of about 1 cylinder every 5 minutes, or 12 per hour.

(4) To reduce this excessive figure, attempts were made to use various arrangements of mouthpieces and one-way valves to circulate exhaled air through an absorbent which chemically removed the CO_2. This apparatus was exceedingly clumsy and inconvenient to the diver, and the increased density of the gas under pressure increased resistance to breathing so much that the idea was discarded as impractical. Therefore, further application of physical laws was made to let the incoming gas do the work of recirculation by a well-known principle (Venturi's) by which a rapidly moving jet of gas tends to drag surrounding gases along with it, creating a suction-pump effect. By proper design, this jet arrangement has been made to recirculate approximately 11 times its own input volume, so that only about ½-cubic-foot-per-minute makeup gas expended within the helmet is needed for adequate ventilation and absorption of the CO_2. By this means, helium-oxygen diving has been made practical.

Special Training Required

(5) Because the technique of preparing and using helium-oxygen mixtures is entirely different from and more complicated than air diving, a special program of training is included in the courses of instruction given at the Naval School, Diving and Salvage. Each student, before being designated a diver first class, is taught the principles and practical application of mixing and use, including qualifying dives to depths of at least 320 feet.

Preparation for Descent

(6) A standard deep-sea diving dress with gloves in good condition is worn. The breastplate nuts must be well set up to avoid any leaks. A full belt and standard $He\text{-}O_2$ double-soled shoes, weighing approximately 35 pounds each, are used. Inspect the connections to the helmet to see that they are tight and properly made up. A safety nonreturn valve must be used. See that the aspirator high-pressure nozzle is clear and clean. Screw the helmet on the breastplate, open faceplate, attach control valve to breastplate, then stop lifeline to right side of breastplate and hose to left side. Test the intercommunication system.

(7) Prior to securing to the helmet, the canister should be checked to insure that it is properly filled and that the screen has been placed in the left (discharge) connection and that a neoprene or Koroseal washer is in each connecting nut. Then attach the canister to the helmet, setting up on the nuts with a wrench. Next turn on the helium-oxygen supply with a pressure of 50 psi and listen to the sound of the aspirator. The diver then opens and closes the control valve to test it and the nonreturn valve. As soon as the exhaust valve and faceplate are closed, the diver is checked for leaks and a voice change, then he will be ready to enter the water.

(8) There should be no leaks anywhere in the dress and none at all in the recirculating system, particularly the canister. The entire operation of dressing is done more conveniently with the diver seated on a stool. He should be lowered into the water on a stage because the weight and balance of the dress make it very difficult for the diver to handle himself out of the water.

(9) Prior to descent, it is imperative that the master diver know that the diver's supply lines have been flushed of all other gases by the mixture to be used and that the diver is actually breathing the $He\text{-}O_2$ mixture. This can be de-

tected quite accurately by both the diver and his tender, because a change of voice pitch occurs when breathing helium. This precautionary measure is particularly important when several hundred feet of diving hose are used. In the case of the initial dive of the day, the length of hose will probably contain air. For subsequent dives, the line will contain pure oxygen left over from the previous diver's decompression. A case of oxygen poisoning, at 300 feet, is on record where this procedure was not followed. It was calculated that the oxygen left in 600 feet of hose from a previous dive momentarily furnished the affected diver with a 40-percent oxygen mixture when bottom was reached.

Procedure During Descent

(10) During the descent, the diver uses his control valve to keep the dress properly inflated. When he reaches the bottom, the control valve is closed after a thorough ventilation. The recirculating system then replenishes the oxygen and provides the necessary ventilation. The exhaust valve is kept closed, the diver using his chin valve occasionally to regulate buoyancy. The control valve may be opened if the diver needs a sudden increase of gas in his dress.

(11) When he receives the order "Ventilate," the diver opens his control valve about one-quarter turn and holds the chin valve open. This is done either to renew the atmosphere in the dress completely, or to remove the helium-oxygen mixture from the dress when shifting to pure oxygen during the decompression. The diver may ventilate his dress at intervals on the bottom if he is working hard, or if he is not satisfied with the adequacy of the recirculating system.

(12) At the order "Circulate," the diver closes his control valve and releases the chin valve, permitting the recirculating system to supply him.

(13) The order "Go on open circuit" means to operate the outfit in the same way that the conventional compressed-air outfit is used. First, open the control valve, then open the exhaust valve, and finally close the Hoke valve. This must be done if the recirculating system fails. If the diver notices from the sound of the aspirator jet that the circulating system is not working, he should shift at once to "open circuit," reporting his action via the intercommunication system and by signal.

Conversation in Helium Atmosphere

(14) The acoustical properties of diver's intercommunication have generally been poor. When diving with helium-oxygen, the density of the mixture being different from air, a peculiar quality is imparted to the sound of the voice. This makes it difficult to understand the diver. Experimental types of intercommunication systems with tone control built into the amplifier have given better results. With experience, men learn to adapt their voices somewhat to the helium atmosphere. It is excellent practice for the diver to speak over the intercommunication system about once a minute during the dive. A continuous description of the conditions he encounters and a report of what he is doing will give him something to talk about and may be extremely useful information.

Hand Signals

(15) The following special hand signals with lifeline and air hose seized together are prescribed for use in case the telephone fails:

3 and 2 pulls "Ventilate" or "Go on open circuit."

4 and 3 pulls—"Circulate."

When made by the diver, these signals indicate that he is carrying out the operation indicated.

Procedure During Ascent

(16) During the diver's ascent, the speed of ascent to the first stop and the time spent at the subsequent stops, breathing helium-oxygen mixture or oxygen, are specified in the decompression tables. Use a rate of 60 feet per minute between stops.

(17) Undressing is done most easily with the diver seated on a stool. Open the faceplate, remove the canister, unfasten the lifeline, air hose, and control valve from the breastplate, and remove the helmet. Proceed with undressing in the same manner as with the compressed air outfit.

Decompression With Helium-Oxygen Mixtures

(18) The characteristics of decompression with helium-oxygen mixtures are different from

those of air. With the former, a larger volume of gas is concentrated in the faster saturating parts of the body, and the rapid diffusion of gas from one part of the body to another, on reduction of pressure, requires keeping the body at high pressures for a longer time during the primary period of decompression. Also, the normal procedure for decompression after a helium-oxygen dive is to have the diver breathe pure oxygen beginning at the 50- or 40-foot stop. Because pure oxygen should not be used at depths greater than 50 feet, and then only while resting during decompression, the decompression must be made on helium-oxygen mixtures up to that point. In case of necessity, however, the diver can be decompressed on helium-oxygen mixture throughout, or shifted to compressed air, subject to a separate and distinct procedure for use in each of these two cases. In shifting to compressed air at depths in excess of 165 feet, onset of nitrogen narcosis is rapid, with symptoms of lightheadedness, dizziness, and possibly loss of consciousness developing. In actual practice, a gradual shift from helium to air is accomplished, whenever possible, through use of the recirculation system, by the diver's continuing to "circulate" after the shift to air for 20 minutes of decompression time, without "ventilating," before he goes on "open circuit." The helium-oxygen decompression tables in section 1.5.4 are accordingly different from those used for ordinary compressed-air diving.

Oxygen Concentrations To Be Used

(19) For any given dive, the percentage of oxygen in the breathing mixture must be limited so that, at maximum depth, the effective partial pressure of the oxygen is not greater than 1.6 atmospheres absolute. The maximum percentage for any given dive may be obtained from the following formula (D=feet of sea water):

$$\text{Maximum percentage of } O_2 = \frac{(1.6\times 33)}{(D \text{ gage}+33)}\times 100$$

The minimum oxygen percentage to be used in diving to depths of 380 feet or less is 16 percent. This limitation is necessary because of the way in which decompression stops were computed. During decompression, the diver can be shifted to a low-pressure bank on the manifold which contains not less than 16 percent oxygen. A considerable saving of gas is effected. The partial-pressure table does not change, as it is based on depth and percentage of oxygen while on the bottom.

Use of Helium-Oxygen Decompression Tables

(20) Helium-oxygen decompression tables differ from the air tables in the following major respects:

(*a*) The partial pressure of the inert gas on the bottom, and not the depth of the dive, determines the particular table to be used.

(*b*) The rate of ascent from the bottom to the first stop is given in the particular table used.

(*c*) The time of ascent from one stop to the next is included in the time of the subsequent stop.

The procedure for using helium-oxygen decompression tables is as follows:

Procedure:

1. Determination of depth:

Assume a depth of 297 feet. This is most accurately measured by means of an air supply, a depth gage, and a length of oxygen hose. The hose is attached to a weighted line and lowered to the bottom. Air is blown through the oxygen hose until it escapes from the open end. The air is then secured and the air pressure remaining in the hose is read on the depth gage. This value gives the depth to the accuracy of the gage calibration. It is recommended that a similar hose be made up with the diver's lifeline and air hose so that the depth of the dive may be determined with accuracy at intervals during the dive. Depth readings by fathometer, lead line, stage line, and descending line are subject to large and varying errors (1.4.7(13)).

2. Oxygen percentage to be used:

Determine the maximum percentage of oxygen permissible by the formula given in 2.5.3 (19) for a dive with bottom time less than 30 minutes:

$$\text{Maximum } O_2 = \frac{1.6\times 33}{297+33}\times 100$$

$$= \frac{52.8}{330}\times 100$$

$$= 16.0 \text{ percent}$$

Load the helium-oxygen manifold, assuring that the oxygen content of the highest and lowest flasks in one bank does not vary by more than 2 percent. Flasks are placed in the manifold so that the average of the flasks in each bank is as close as possible to the oxygen percentage desired. A satisfactory form, such as the following, should be provided for recording helium-oxygen mixtures:

Date ________________

$He-O_2$:

Bank in use:

No. ________; Pressure ________ psi;

Percent O_2 ________

Standby bank:

No. ________; Pressure ________ psi;

Percent O_2 ________

Bank in use:

No. ________; Pressure ________ psi;

Standby bank:

No. ________; Pressure ________ psi

3. Selection of decompression table:

Determine the partial pressure (PP) of all other gases (AOG), except oxygen for the depth of the dive. Assume that the bank to be used averages 16.0 percent oxygen.

$$\text{PP of AOG} = (D+33) \times (100 - (O_2 \text{ percent} - 2)) \text{ percent}$$

A loss of 2 percent oxygen in the helmet is assumed.

Thus, for a depth of 297 feet and an average of 16.0 percent oxygen in the bank, the partial pressure will be:

$$\text{PP of AOG} = (297+33) \times (100 - (16.0 - 2)) \text{ percent}$$

$$= 330 \times (100 - 14.0) \text{ percent}$$

$$= 330 \times 0.86$$

$$= 283.8$$

As no interpolation of the decompression tables is permitted, use the next higher tabulated decompression table, which is for a PP of 290. The partial pressure table gives the PP of AOG for various depths and for various percentages of oxygen. To use, enter the table with the depth by gage and the average oxygen percentage of the bank to be used.

4. The descent:

When the diver is dressed with the faceplate closed and the Hoke valve open, have him start counting and ventilating in order to flush the air hose and helmet. The characteristic voice change will show when the diver is breathing helium-oxygen. The diver is then hoisted over the rail and lowered in the water while on the stage. A careful visual check of the helmet and suit is made for leaks. When the diving officer is satisfied that all is in order, the diver is signaled to commence his descent. The rate of descent should not exceed 65 feet per minute. Frequent short ventilations should be made during descent and upon reaching the bottom. The frequency of ventilation while on the bottom depends upon the conditions of work and currents.

5. The ascent:

(*a*) The "time of dive" used in the tables is "bottom time," or the total time from leaving the surface to leaving the bottom. Assume 9 minutes as "time of dive." The correct decompression schedule is partial pressure 290, "time of dive" 10 minutes.

(*b*) The first stop:

The rate of ascent from bottom to first stop is determined as follows: Time to first stop, 4 minutes (from decompression table, partial pressure 290); first stop, 110 feet (from decompression table); distance to first stop equals depth of dive minus depth of first stop, or 297 minus 110, or 187 feet; 187 divided by 4 equals 46.75 feet per minute. Bring the diver up to 110 feet at the uniform rate of about 47 feet per minute, and keep him at the first stop for 7 minutes. During decompression, while breathing $He-O_2$, pressure is maintained at 100 psi over bottom pressure, only when shift is made to O_2 may pressure be reduced to 50 pounds over bottom pressure. When the shift is made to the lower pressure, the noise level of the jet operation is greatly reduced. This results in greater comfort for the diver and in better voice communication.

(*c*) The second stop:

The second stop, at 80 feet, is for 3 minutes. The rate of ascent from the first stop to the second is 60 feet per minute.

Use 30 seconds for the ascent. Keep the diver at 80 feet for 2½ minutes.

(*d*) The third stop:

Three minutes from the time of leaving 110 feet, the first stop, proceed to 70 feet, the third stop. The rate of ascent is 60 feet per minute.

(*e*) The fourth stop:

Three minutes from the time of leaving 80 feet, the second stop, proceed to 60 feet, the fourth stop.

(*f*) The fifth stop:

Four minutes from the time of leaving the 70-foot stop, bring the diver to 50 feet. Shift the diver's gas supply to oxygen on the manifold. Ventilate the diver with 25 cubic feet of oxygen, and then have him circulate for the remaining time of the stop. Twenty-five cubic feet of oxygen at atmospheric pressure is equivalent to a 225-pound pressure drop in one cylinder. The total time of the 50-foot stop is the sum of the individual times of the following three distinct times.

1. Time of ascent from previous stop at 60 fpm.

2. Time of ventilating the diver with 25 cubic feet of oxygen.

3. Time of circulating on oxygen.

Do not exceed the time as given in the decompression tables. In the computation of this stop, 3 minutes are allowed for the time of ascent and the time of ventilation.

(*g*) The sixth stop:

Ten minutes from the time of leaving the 60-foot stop, start the diver to 40 feet.

(*h*) Surfacing:

Forty-two minutes from the time of leaving the 50-foot stop, the decompression is complete. Surface the diver at a rate of 40 feet per minute, during the last minute of the decompression time.

Be familiar with the safety precautions as summarized in section 1.5.4(21), and be ready to take prompt action in the event of oxygen poisoning.

Partial pressure and decompression tables for helium-oxygen diving are contained in 1.5.4. This article also contains and discusses the table for emergency use of helium-oxygen or air for decompression. Paragraph 1.5.4 should also be consulted for supplemental information. Because surface decompression is widely used following helium-oxygen diving, 1.5.5 concerning that subject should be reviewed at this time.

2.5.4 TENDING THE DIVER

Responsibility of Tenders

(1) This subject is discussed in 1.4.7. An additional and more detailed discussion and practical instructions of an operational nature are given herein.

(2) Before sending the diver down, the tender must thoroughly check such items as exhaust valve, control valve, dumbbell, intercommunication system, and breastplate nuts. When it is certain that the diver is properly dressed and ready, the tender, with the assistance of another tender, should take a firm grip on the lifeline close to the helmet and guide the diver to the stage or ladder. Care must be taken to prevent the diver's losing his balance, stumbling, or falling. When the diver has adjusted his flow of breathing mixture and all is ready, he should be directed to the descending line. The proper signal will be given when it is time to descend. From the time the diver leaves the deck of the ship until he is safe on the bottom, the tender must keep all slack out of the line and be ready to render assistance at a moment's notice.

Signals

(3) Because signals cannot be received on a slack line, the lifeline and air hose should be kept well in hand so that signals can be made distinctly. The tender, on receiving a signal, shall repeat it only if it is clearly understood. If a signal is not repeated, it indicates to the diver that the signal is not understood and should be repeated. If a wrong reply is received from the diver, the signal should be repeated until it is correctly understood.

(4) When the diver is on the bottom and near the descending line, the descending line should be watched for signals, as the diver may want it lowered or the slack taken up. If at any time there is anything seriously wrong, the diver should ask to be hauled up by signaling four pulls on the air hose and lifeline. Four pulls on the lifeline repeated is the emergency signal and should never be used unless something serious has happened; the tender must not delay in obeying it.

(5) If the diver does not answer a signal after two or more trials at short intervals, he should be asked, over the intercommunication system, if he is all right. If he answers the intercommunication system, it may be that there was too much slack in his lifeline and air hose or that the line was fouled. The reason should be determined and corrected. It should be remembered also that a diver at work may not be in a position to answer pull signals for several seconds and he should be given a reasonable length of time to answer. If the diver does not answer either the hand signals or the intercommunication system, he should be brought to the first decompression stop and the standby diver should be sent down to the stop to determine the trouble and to be of assistance. During this time, continued efforts should be made to contact the first diver by using all means of communication. (See art. 1.6.16 for additional information.)

Intercommunication System

(6) When hand signals are used, the information and instructions exchanged between diver and tender are necessarily restricted to either standard diving signals or special prearranged signals. The intercommunication system is provided with the deep-sea diving outfit, thereby making it possible to relay and receive detailed instructions via voice communications. The tender hearing difficulties for the diver above the gas noise level make it imperative that conversation with him be only that which is essential. The diver should be instructed to make continuous reports at regular intervals while on the bottom and ascending. This procedure serves to keep the diving officer continuously informed, while the tender need only acknowledge reports received. It is annoying and time consuming for the diver to have to stop work to listen and reply to extraneous messages. The man assigned to the intercommunication equipment as a talker should have diving experience and a clear speaking voice. This will result not only in reducing the frequency of communications but will afford an additional factor of safety.

(7) If either the diver or tender fails to get an answer over the intercommunication system, the hand signal should be made to indicate to the other that he is trying to talk. After the diver has repeated the hand signal, the tender should wait a few seconds and try the intercommunication system again. Then if no answer is received, it should be assumed that the intercommunication system is out of order and the hand signals should be restored. If, on the other hand, after answering a message over the intercommunication system, the same message is repeated several times and no attention is paid to the answer, the person receiving the message should acknowledge that he understands it by signals. Failure of the diver's intercommunication system may be detected by the tender through a sudden stoppage of gas noise and other sounds from the diver's helmet.

(8) In deep water, when a strong tide is running, the hand-signaling method is very difficult and often impossible. Therefore, diving under these conditions should not be attempted unless the intercommunication system is in good working order. Under these circumstances, if the intercommunication system should fail, the diver should be brought to the surface in accordance with the proper decompression schedules and the standby diver sent down to assist him and ascertain his condition.

Diving Log

(9) One tender should be assigned to stand by the intercommunication system, all the time the diver is down, to receive and relay instructions. In addition, the intercommunication system attendant should make the entries on the diving log. The time entries on the log should be very accurate, as it is from these entries that the diving officer determines the proper decompression time for the diver. If there is any doubt as to the time that the diver has spent on any phase of the dive, the time allowance is made to give the diver longer decompression. (See art. 1.8.4 for additional information concerning the diving log.)

Tending the Lines

(10) In tending the diver's lines, the tender should make certain that the lines are not held too taut; otherwise, the diver will find himself being continually pulled away from the work. In attending the lifeline and air hose, the diver should be given 2 or 3 feet of slack when he is

on the bottom, but not so much that he cannot be felt from time to time.

(11) If the combined lifeline and air hose becomes turned around the descending line, it may become impossible to send or receive signals by this means, and the turns must be taken out as soon as they are noticed. If, after a trial, they cannot be cleared, the diver should be hauled up. It may become necessary to haul the diver up along with his descending line and weight. In this event, if the weight is too heavy, the diver should try to cut it adrift and time should be allowed him for this purpose. Because of the possibility of his lines becoming fouled around another line, a diver ordinarily should not be permitted to descend on a line he cannot cut. However, on occasion it may be imperative or highly desirable to use a steel rope or chain. The selection of the descending line to be used is left to the judgment of the officer or diver in charge.

Conditions Indicating Diver's Location and Operation

(12) The tender can very definitely use the bubbles rising to the surface to assist in determining how the diver is faring. The bubbles give an indication of the diver's movements on the bottom, and the tender, having a knowledge of the work to be done, can generally tell whether the diver is proceeding satisfactorily. If the diver is searching and the mass of bubbles appearing on the surface seems to be moving in a somewhat definite pattern, or if a job requires the diver to stand in one spot and the bubbles come to the surface in one small area, it is reasonable to assume the diver is proceeding safely.

(13) In addition to the above, it is possible to determine where the diver is and how he is doing by the following methods which are briefly described:

(*a*) The operation of pneumatic drilling machines can be detected by feeling the supply air hose at almost any point because of the peculiar variation of pressure within the hose when the machine is actually running.

(*b*) The operation of a pneumatic hammer can be detected in the same way. When divers are working with pneumatic hammers or with hand hammers and chisels of fairly large size, it is also possible to hear every blow that is made by listening in the after hold of the salvage vessel.

(*c*) The operation of an arc torch can be detected by observing the ammeter connected in series with it.

(*d*) The operation of a gas torch may be detected by indication on adjacent gages of the flow of gas past the reducing valves. Also, when the torch is lit, the noise can almost invariably be heard over the telephone of the diver who is operating it; also, the large bubbles of gas from the torch break on the surface and emit small bubbles of smoke.

Precautions To Prevent Diver's Falling

(14) Whenever a diver is working clear of the bottom, as on a ship's deck or on a stage under a ship, the tender should take all necessary precautions to prevent his falling. If under certain conditions it was noted that the bubbles were moving rapidly in a straight line, it would indicate that the diver had fallen. In this event, all lines should be tightly gripped and the slack quickly gathered in until the descent is checked; then the diver's condition should be determined. In any case where there is danger of a fall, a tight hold should be kept on the diver's lines and a minimum amount of slack let out.

Emergency Ascent

(15) In bringing the diver to the surface, the tender should make certain that the rate of ascent does not normally exceed 60 feet per minute. In case of accident or emergency, it may be necessary to bring a diver to the surface as rapidly as possible, despite the risk of decompression sickness. Examples of this might be evidence that the diver is in immediate or imminent danger of blowing up or that the diver is unconscious or in extreme distress. Under these conditions the speed of the ascent will depend on—

(*a*) Nature of the accident or emergency.

(*b*) Depth and length of exposure of the dive.

(*c*) The proximity of a recompression chamber for immediate use.

Regardless of the above, an emergency ascent to the surface should not be started until the standby diver has been sent down to investigate the nature of the difficulty.

(16) When the diver fails to answer his signals, the procedures outlined in 1.6.16 should be employed. These procedures are also applicable for other emergencies.

(17) If a diver loses his distance line and cannot locate his descending line, it becomes necessary for his tender to pull him up and not waste time searching for the descending line. The tender should always keep the diver ascending very slowly until he reaches the decompression stage. The tender should cease hauling in the line if it is found that the diver is becoming too light, but should continue to take in all slack of the lifeline. Trouble in this respect may be experienced when the diver is unconscious or helpless. The diver should not be brought up beyond his first stop as indicated by the decompression tables. As the diver reaches this stop, he may be worked over to the decompression stage, and if he is conscious no trouble will be experienced in landing him on it. If it is impossible for the diver to find his descending line or the stage after reaching the first stop, the standby diver should be sent down the descending line while holding the first diver's lifeline and air hose in the loop of his arm until the situation is corrected.

SECTION 2.6 SUMMARY

2.6.1 SUMMARY OF SAFETY PRECAUTIONS

Diver Must Be Qualified

(1) Never put a man down who is not a qualified diver, except for training dives.

(2) Never put a diver down whose qualification has lapsed, except in case of an emergency or to requalify under adequate supervision.

(3) Never exceed depth to which diver is qualified.

(4) Never send a diver down who has been physically disqualified.

(5) Never dive a man until he has passed the physical examination outlined in the *Manual of the Medical Department*.

(6) Never dive a man unless he is schooled properly in operating the type of diving outfit he is to wear.

(7) Never dive a man if he does not know the diving hand signals.

(8) Never dive a man if he has consumed excessive alcohol in the preceding 24 hours.

(9) Never dive a man if he is suffering from a severe cold, sinus or ear trouble, or an acute illness.

(10) Never dive a man who is subject to fatigue from loss of sleep or previous severe physical or emotional strain.

(11) Never exceed the depth limitations of 1.4.1(11), except as stated therein.

2.6.2 DIVING EQUIPMENT

(1) All equipment must be in first-class operating condition.

(2) The control, nonreturn, and regulating escape valves shall be inspected daily before diving commences and must operate satisfactorily at all times.

(3) The leather items should be checked and oiled to prevent deterioration.

(4) The helmet fittings—safety lock, windows, goosenecks, air passages, gaskets—should be securely in place and free from all obstructions or verdigris.

(5) The diver's air compressor must be properly lubricated, cooled, and cleaned, both during use and stowage. If the compressor is not used, it should be broken out every 30 days and operated, and again prepared for stowage.

(6) The recompression chamber must be ready for use at all times.

(7) All flammable material possible should be removed from the chamber.

(8) Only fire-retarding paint should be used in the chamber.

(9) No open flames, matches, cigarette lighters, lighted cigarettes, or pipes shall be taken in or used in the chamber during its use.

(10) Decompression tables and treatment tables should be located on the inside and outside of the chamber.

(11) The diver's lifeline and air hose shall be led over a roller or suitable curved place on the gunwale to avoid sharp bends that could break the conductor wires or core or damage the rubber cover.

(12) Many solvents and cements used with diving equipment are toxic and/or flammable. Appropriate safety precautions shall be observed in their handling (see app. C).

2.6.3 PLANNING DIVING OPERATIONS

(1) Never start any diving operations without the presence of a qualified officer. If such an officer is not available, a qualified diver should be placed in charge.

(2) Never send a diver down without having immediately available the means of sending down a relief diver and without being able to maintain both divers on the bottom for a reasonable length of time. For shallow-water diving, the diver may be backed up by a standby equipped with a lightweight outfit or scuba. For deeper dives, the standby diver must be dressed in a deep-sea outfit except for his helmet,

with communications tested and air supplied up to his control valves. For He-O_2 dives of over 200 feet, while the diver is below his first decompression stop, the standby must be completely dressed in an He-O_2 outfit. It is recognized that special circumstances on the scene may require the diving officer to modify the above in some cases.

(3) Never rely on charts or hearsay as to depth of water when diving, but have a qualified man take soundings with a lead line or preferably, determine depth with a pneumofathometer. If an area is being searched, soundings should be repeated from time to time.

(4) Never undertake diving operations without having a decompression table readily at hand. If decompression is contemplated, a stage should be rigged and stage line marked at 10-foot intervals as described in 2.1.5 (4) and (5).

(5) In all cases where diving operations are to be undertaken, the depth of water and fatigue of the diver should determine the diver's time on the bottom instead of the amount of work to be done.

(6) A diver should never be allowed to descend without first determining his decompression time for his expected time on the bottom.

(7) Foresight used in the sound planning of a diving or salvage operation is half the job. Emphasis is often laid on the emergency of the job, resulting in men and equipment arriving at the scene of operation unprepared.

(8) Planning is paramount if systematic locating operations are to be undertaken from the surface, but in most cases this method is easier, quicker, and more accurate than that of the diver with his circling line.

(9) No diving locker is considered complete without equipment for performance of the following in a manner commensurate with the capacity of the men available:

(*a*) Location and search equipment adequate to search a given area properly, including buoys and anchors for marking such areas.

(*b*) Adequate and safe diving equipment for two divers.

(10) Do not send a diver down unless he thoroughly understands what he has to do when on the bottom. This is important. Use sketches, blueprints, or inspection of a sister ship of the sunken vessel if available. If the diver does not fully understand his task, it is useless to send him down.

(11) Never make a dive unless the available air supply is sufficient for all dives planned, plus an adequate reserve for a relief diver in event of an emergency.

(12) Never put a diver down unless the boat or ship is in at least a two-point moor.

(13) Never send a diver down unless the proper naval or international diving signal is flying.

(*a*) Are you displaying the proper signal? FOUR Flag (inland).

(*b*) If diving in international waters, either of the following hoists is correct:

"Underwater Task" shapes—red ball, white diamond, red ball, spaced 6 feet apart.

International diving hoist: code pennant, FOXTROT-CHARLEY-ZULU.

(14) Never attempt to shift moor while a diver is down.

(15) Never turn the propeller or get underway while a diver is down.

(16) Never send a diver down on the propeller of a ship without first taking proper precautions (2.5.1(1)).

(17) Never send a diver down around the hull of a submarine until the duty officer has been notified not to operate bow planes, stern planes, sound heads, rudder, or propellers.

(18) Never set off an explosive charge when a diver is down.

(19) Never let a diver work around corners or inside a wreck without the help of another diver to tend his lines from the point of entry.

(20) A diver should never cut a line until he has made certain of the purpose for which it is being used.

(21) Prior to all diving, the diver should remove from his mouth anything that might tend to choke him (dentures, gum, etc.).

(22) Never put a diver down while ship is drifting, except for critical emergency repairs to ship.

2.6.4 DRESSING THE DIVER

(1) Never dive without a safety nonreturn valve on helmet or mask; always check this valve for proper working order.

(2) Never dive with a helmet without first checking the exhaust valve.

(3) Never dive with a handpump without knowing its efficiency or without overhauling it if the efficiency has dropped too low.

(4) Never attempt any diving operations if the compressor is not operating satisfactorily or gives any indication that it will not continue to operate satisfactorily.

(5) Never connect a diver's air hose directly to the delivery nozzle of a diving compressor or diving pump; an oil separator and volume tank are required.

(6) Never dive without first checking jockstrap for possible breakage.

2.6.5 THE DESCENT

(1) Never allow a diver to descend without a final check to insure that—

(*a*) The helmet is tightened securely and the helmet lock is locked in place.

(*b*) The air hose and lifeline are securely tied to the breastplate.

(*c*) The exhaust valve is set.

(*d*) The control valve is opened and air is passing through the suit.

(*e*) The diver makes a sound test of the nonreturn valve seating.

(*f*) Telephone communications are in good order.

(*g*) The jockstrap is tightened properly.

(*h*) The faceplate is securely closed.

(*i*) The diver has a ready, pure, and adequate supply of air, or other breathing medium, at the proper overbottom pressure, and that this pressure is maintained.

(*j*) The descending line is properly placed.

(*k*) The diver gives his signal to descend.

2.6.6 WORKING ON THE BOTTOM

(1) To work efficiently and safely under water, a diver must keep in mind the following:

(*a*) Never completely close the air-control valve, except in case of rupture or replacement of air hose.

(*b*) The helmet air-regulating exhaust valve stem, known as the chin valve, may be used effectively to release quickly the suit pressure when there is a need to stoop or crawl on the bottom without changing the air-control valve and the air-regulating exhaust valve adjustment.

(*c*) The helmet spitcock offers another method of relieving excess pressure in the helmet.

(*d*) The safety nonreturn valve in the helmet gooseneck and the helmet air-regulating exhaust valve will seat themselves if the diver's air supply is impaired, but the spitcock, if open, must be closed immediately by hand.

(*e*) A diver is never in danger from a leaking dress, provided he remains in an upright position.

(*f*) Air trapped in the diving helmet will last from 6 to 9 minutes for breathing purposes after the diving air is cut off; thus there is ample time for emergency measures to be executed, provided the diver does not get excited or exert himself.

(2) Never leave a diver on the bottom in sudden squalls, heavy seas, strong tides, or any other conditions that, in the opinion of the commanding officer, jeopardize the security of the moorings.

(3) Never weld or burn under water with alternating current when direct current is available. See *Underwater Cutting and Welding Manual* (NAVSHIPS 250–692–9) for information.

(4) Never perform electric welding or burning under water except in extreme emergency, unless a diver is wearing a complete suit to fully insulate his body from the work, the torch or electrode holder, and the water itself. The use of rubber or rubberized canvas gloves, bonded to the suit, is mandatory. The diving outfit in use must be fitted with voice communications.

(*a*) If lights are required, examine them and the extension cord to insure good condition. Also insure that the plug is properly grounded at the receptacle.

(5) When working about moorings, or wreckage, a diver should be especially careful not to get fouled. He should not dip under chains or lines. He should, if possible, always go over obstacles instead of under them. This is especially important because of the danger imposed in the event of a "blowup" later in the dive. A diver should not descend on a chain or wire if it is possible to do otherwise, and neither should a chain, wire, line, or weight be veered,

lifted, or moved until the diver has been brought up.

(6) Whenever a diver discovers that he is fouled he should not become excited but should attempt to extricate himself by slow, methodical steps. The distance line should never be released, as it is a safe guide and should show the way out of a tangle. He should inform the surface crew to slowly take up the slack in his air hose and lifeline. After resting and again attempting unsuccessfully to free himself, he should ask for help.

(7) In case a diver is fouled and cannot extricate himself, a relief diver who is sent down must be prepared to replace both air hose and lifeline, a procedure that may be safely executed on the bottom.

(8) When a diver is working on the bottom of a ship, he should always have something substantial to hold on to, and should have the tenders keep the lifeline and air hose well in hand. It is dangerous for a diver to hold on to something overhead while climbing, as all the air in the dress may escape from the cuffs or through leaks in a torn glove, in which case he may become heavy and fall. He should never go under the keel of a ship and up on the other side. If it is necessary to work on the other side, he should come up and redescend or walk around the ship.

2.6.7 TENDING THE DIVER

(1) Never allow a dressed diver to walk on topside, unattended.

(2) Never let a man who does not know his signals tend a diver.

(3) When a diver is going down a ladder, the tender must keep both hands on the lifeline and air hose, and must be backed up by another man.

(4) Do not allow air hose and lifeline to run free when diver is descending.

(5) Do not give diver too much slack while he is on the bottom. To do so increases the chances of fouling.

(6) Do not try to send hand signals to diver without first taking up all the slack.

(7) Do not give signals with long heavy jerks as diver may be hurt in doing so. Signals are to be short and distinct pulls. Never belay a diver's lifeline and air hose to a clear or a stanchion.

(8) Never give a diver too much slack where there is any danger of a fall. Keep a tight hold on the diver's lines and do not give out any more slack than necessary.

(9) "Fish" the diver occasionally, taking in all slack gently and then paying the line out again as necessary. This is a good way of telling if the diver has shifted his position. An expert tender can do this without the diver's knowledge.

(10) In case a diver is "blowing up," the tender should take in his slack as fast as he ascends and haul him in on reaching the surface. A check of the diver and equipment must be made before descending again.

(11) A good tender can help a diver considerably. A poor one is a menace.

(12) Never use a man as a tender who does not understand the dangers of a "squeeze" or "blowup" and what to do under the circumstances.

(13) The tender should be constantly on the alert. He should never stand where there is a chance of being pulled into the water. When the diver is going down or coming up, make sure the tender is backed up by someone.

2.6.8 LIGHTWEIGHT DIVING

(1) Never ditch a mask while on the bottom except in an emergency, and then remember to exhale continuously while ascending.

(2) In lightweight diving, do not send a man down who is not a qualified diver and a first-class swimmer.

(3) Never dive without a lifeline attached around the diver's waist. This line must be securely fastened above the weight belt and inside all straps.

(4) In helmet and mask diving, the diver must be able to rid himself instantly of all equipment except his lifeline, in case it becomes necessary to swim to the surface. Only a belt with a quick release shall be used.

(5) It is well to remember that mask, helmet, and "soft" suit diving can, because of its simplicity, become the most dangerous type of diving if not properly supervised.

(6) Never, except in extreme emergency, dive inside a ship or in any other situation

which would not allow a direct ascent to the surface.

2.6.9 HELIUM-OXYGEN DIVING

(1) The safety precautions covering procedures, equipment, methods of working on the bottom, etc., when standard equipment is used apply to helium-oxygen diving.

(2) Do not undertake diving operations until a sufficient quantity of gas has been prepared and has been checked to determine that it is of proper composition.

(3) Make certain that the aspirator and canister are functioning properly.

(4) Maintain 100 pounds gas supply pressure over bottom pressure, except during oxygen decompression or decompression at depths of less than 120 feet when the pressure may be reduced to 50 pounds over bottom pressure.

(5) While on the bottom, if the diver develops symptoms of inadequate ventilation, he should not hesitate to bypass the venturi supply by periodically opening his control valve as conditions warrant. To compensate for this excess supply, the chin button will have to be used more frequently to prevent "blowup." Upon reaching the surface, an investigation into the cause of the inadequate ventilation should be immediately undertaken.

(6) While breathing oxygen at the 50- and 40-foot stops, the diver must keep any form of exertion or exercise to an absolute minimum because increased activity increases susceptibility to oxygen toxicity.

(7) Prior to putting the diver down, ventilate the hose to insure that the diver is actually breathing a helium-oxygen mixture. The change in tone of the diver's voice as he begins to breathe helium is distinct and easily recognized.

(8) Divers must be alert to recognize the symptoms of oxygen poisoning while at the oxygen stop. At the first indication of trouble, diver should notify topside and stand by to ventilate. The diving supervisor should immediately order the manifold to shift to air or helium-oxygen and the diver to ventilate. The symptoms of oxygen poisoning include nausea, twitching of muscles, ringing of the ears, visual disturbances, and dizziness.

U.S. NAVY DIVING MANUAL

PART 3

SELF-CONTAINED DIVING

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SECTION 3.1 INTRODUCTION

3.1.1 GENERAL

(1) Self-contained underwater breathing apparatus (scuba) was developed to allow complete freedom of underwater movement. It allows dives that are free of encumbrances and independent of a surface supply of air.

(2) "Self-contained" indicates that the diver carries his breathing medium with him. Three types of scuba are in present use. Each type may include more than one make or model, but the basic principles and characteristics are essentially the same for all units within the type.

(*a*) Demand-type (open-circuit) scuba is the simplest type and the one most frequently used. The diver carries large cylinders which are normally charged with compressed air. A demand regulator provides air to the diver when he inhales, and the air is exhausted into the water when he exhales. The fact that air flows only in response to inhalation requirements helps conserve the supply, but the limited duration of the amount of air the diver can carry is one of the principal drawbacks of demand-type gear.

(*b*) Closed-circuit scuba employs pure oxygen as the breathing medium. The diver breathes this gas to and from breathing bags; the exhaled gas passes through a canister containing a carbon dioxide absorbent. Normally, no gas is exhausted into the surrounding water. Because the body consumes only a small amount of oxygen compared to the total volume of breathing, a relatively small gas supply suffices. Closed-circuit scuba also has the advantage of freedom from bubbles and noise, a fact which can be very important in some tactical applications. The main disadvantage is the severe limitation of a safe depth of use imposed by the possibility of oxygen poisoning.

(*c*) Semi-closed-circuit scuba was developed to permit conservation of gas by rebreathing without the necessity of using pure oxygen. The apparatus is basically like closed-circuit scuba, but a continuous flow of a gas mixture is provided to assure that neither a lack of oxygen nor excessive high oxygen levels develop. The diver rebreathes the major portion of the gas, but a certain amount is continually exhausted from the system. Much greater durations of submerged time can be achieved with semi-closed-circuit scuba than with demand-type scuba. Generally, mixtures of nitrogen and oxygen (i.e., air with added oxygen) or helium and oxygen are used. These mixtures can sometimes provide an added advantage by shortening the decompression time required.

Importance of Scuba

(3) Experience gained during and since World War II has proved conclusively that scuba is important to the Navy for many reasons. Scuba is in wide use by Underwater Demolition Teams (UDT) as well as by Explosive Ordnance Disposal (EOD) Units. It is also widely used throughout the fleet and on shore stations where easily portable diving equipment is needed for propeller inspections, ship-bottom inspections, and equipment recovery. Scuba is of particular value in tactical operations requiring stealth and is equally valuable in defensive action against similar operations. The Navy Experimental Diving Unit, Naval Operation Test and Evaluation Force and various operational units conduct constant research and evaluation of scuba to provide the Navy with the best equipment available.

(4) In June 1954 the U.S. Naval School, Underwater Swimmers, was established at the U.S. Naval Station in Key West, Fla., to help meet the Navy's growing need for trained scuba divers. This development illustrates perhaps more than any other the increasing realization of the importance of trained scuba divers in the Navy.

3.1.2 COMPARISON WITH SURFACE-SUPPLIED DIVING

General

(1) The diver must know and appreciate the difference between self-contained diving and surface-supplied diving so that he can choose the proper equipment of a specific job. Scuba can replace deep-sea outfits for certain purposes, and can act as lightweight equipment for most shallow-water diving operations. All types of diving equipment have a place in Navy diving. Every operation requires the officers and men involved to have a thorough understanding of the capabilities and limitations of each type of equipment. The best way to compare self-contained diving with surface-supplied diving is to consider the advantages and disadvantages of scuba.

(2) The main advantages of scuba are—

(*a*) Mobility.

(*b*) Depth flexibility and control.

(*c*) Portability.

(3) The main disadvantages of scuba are—

(*a*) Limitations of depth.

(*b*) Limitations of duration.

(*c*) Limitations of exertion.

(*d*) Lack of communication.

(4) The psychological aspects of self-contained diving are also important in any comparison with surface-supplied diving. The scuba diver is exposed more directly to the underwater environment than is the surface-supplied diver. The scuba diver frequently has no contact with the surface by lifeline or telephone. He depends entirely upon his breathing apparatus and its limited gas supply. Even though he has a buddy (a basic rule when diving without surface connections), he must face most of his problems alone. These considerations make a demand for greater self-control on the part of the self-contained diver than in the surface-supplied diver. The scuba diver must have excellent ability to adjust mentally to diving.

Advantages

(5) Mobility is the primary advantage of scuba. The scuba diver has no bulky equipment to hamper any movement. He is free of a hose, and he can be free of an attached line if necessary. At neutral buoyancy he can swim under water in any direction. When necessary the scuba diver may submerge at one point, work at another, and return to a third without surfacing at any time. He can cover considerable distances unaided, and propulsive equipment or submersible craft can greatly increase his operating range.

(6) Depth control is another major advantage of scuba. The equipment is designed to have near-neutral buoyancy when in use. It has a minimum of inherent positive buoyancy and of additional compensating mass. As a result, the scuba diver can change or maintain depth at will. This facility permits the diver to work at middepths without rigging. It also permits him to search deep areas from shallow depths, to drop down to investigate, and to return to shallow depths to continue the search.

(7) Portability is important in scuba (fig. 3–1), because it simplifies the establishment of a diving operation. A large number of scuba rigs can easily be brought to the scene with many divers operating simultaneously.

Disadvantages

(8) The most serious disadvantage of scuba is the DEPTH-TIME limitation. Scuba cylinders have a fixed volume: as the diver goes deeper his volume usage of air increases, thus the time for him to breathe the fixed volume of air in his cylinder decreases proportionally. In open-circuit scuba the gas supply seldom lasts over 3 hours at the surface, and exhausts in much shorter time at depth. In closed-circuit or semi-closed-circuit scuba, the gas supply may last 4 hours or more, but the absorptive capacity of the canister rarely exceeds 3 working hours. These durations are outer limits. Under normal conditions, the duration of a scuba is 2 hours or less. Depth limits of various equipment for operational dives are listed in section 1.4.1(11).

(9) Any scuba limits exertion to some degree. In demand-type scuba, the main limitation is breathing resistance; i.e., inability of the inhalation circuit to deliver gas flow at a high demand rate. In closed-circuit or semi-closed-circuit scuba, it is usually canister capacity; i.e., insufficient absorptive area to take up all the CO_2 in each cycle with a resultant CO_2 buildup.

(10) There are additional disadvantages of scuba: poor communication, minimal protection,

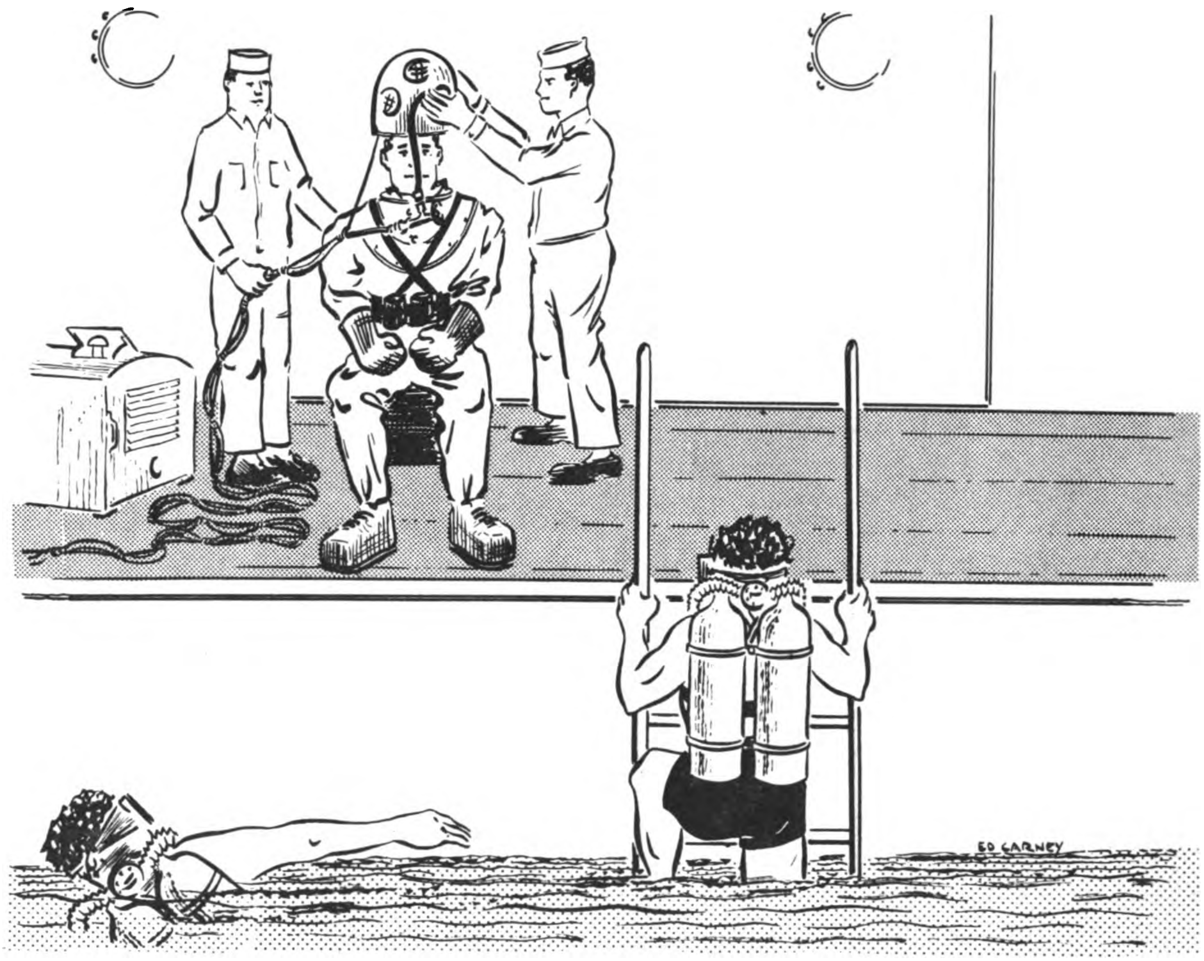

FIGURE 3-1.—Comparison of portability.

and insufficient stability for work in heavy currents. Although these disadvantages are minor, they sometimes make it desirable to use surface-supplied equipment or technique.

Choice of Equipment

(11) The specific situation generally determines the choice between self-contained apparatus and surface-supplied gear. A need for mobility, varying depth control, or portability calls for scuba. Higher requirements of depth and duration make surface-supplied equipment necessary.

(12) Heavy work may be a deciding factor. Breathing resistance sometimes limits the extent of exertion in scuba, especially at greater depths where gas density becomes many times greater than the gas density at the surface. In surface-supplied equipment, the diver has free access to the gas in his helmet, and breathing resistance is at a minimum.

(13) The possibility of great exertion does not automatically dictate the use of surface-supplied equipment, especially if most of the work results from choice of the equipment rather than from the diving situation. Searching a muddy bottom is very hard work for a diver using the heavy surface-supplied dress, and it is much easier work for the diver using scuba. In any situation where heavy gear increases the amount of exertion without yielding any special advantage, scuba may be the logical choice.

(14) Sometimes the choice is not clear cut. Requirements for surface-supplied diving accessories, such as weight and lines, usually cancel the advantages of scuba. In a given situation the

characteristics of different types of scuba may influence the decision.

(15) The safety of the diver is always the prime consideration. Diving supervisors must be well aware of the factors affecting safety. Surface-supplied gear often meets safety requirements best.

Job Requirements

(16) No set of rules can cover all situations, but the following job requirements can help in deciding on the use of scuba for a given job:

(*a*) To cover considerable distances or to move freely under water, scuba is necessary.

(*b*) To move easily over short distances, scuba is desirable, and lightweight surface-supplied gear is suitable.

(*c*) To give free body movement, scuba or lightweight surface-supplied gear is desirable.

(*d*) To stay fixed in one spot, scuba can be used only with weights and lifeline; other rigging may also be required. Surface-supplied gear is usually preferable.

(*e*) To enter enclosed spaces in an emergency, scuba may be required. A lifeline is mandatory and another scuba diver must tend closely.

Exertion

(17) The type of work and the amount of exertion involved may dictate the choice of the most practical equipment to use.

(*a*) For light work, scuba is suitable.

(*b*) For heavy work, scuba is generally not desirable. The lightweight surface-supplied outfit may be suitable, but the heavy rig is generally preferable.

Depth and Duration

(18) Combined considerations of depth and duration of time under water can influence the choice of equipment. Dives requiring decompression time should be avoided.

(*a*) Beyond 130 feet self-contained, open-circuit scuba is unsuitable, except for very short periods.

(*b*) Between 130 and 200 feet, surface-supplied equipment is generally preferable, although scuba is usable if absolutely necessary.

(*c*) Between 60 and 130 feet for moderate durations, scuba is unsuitable. For short durations, scuba is suitable.

(*d*) Between 30 and 60 feet for long durations, scuba may be used. For moderate durations, scuba is satisfactory. For short durations, scuba may be preferable.

(*e*) Between the surface and 30 feet, scuba is suitable for very long durations.

(*f*) Scuba divers must not dive beyond the depths for which they are qualified as indicated in their service records. Normal working depth for scuba using compressed air is considered to be 60 feet, with a maximum working depth of 130 feet. The commanding officer and/or diving officer is responsible for the decision to send a diver beyond the 130-foot maximum working depth limit.

(19) Table 3–1 summarizes the considerations of depth and duration in terms of suitability. In situations where scuba is very suitable, it may be preferable to surface-supplied equipment. In situations where scuba is very unsuitable, surface-supplied equipment is preferable. In situations where scuba is suitable or un-

TABLE 3–1.—*Suitability of scuba for various conditions of depth and duration without regard to type of scuba*

Depth, feet	Duration				
	Very short (0 to 15 minutes)	Short (15 to 30 minutes)	Moderate (30 to 60 minutes)	Long (60 to 120 minutes)	Very long (over 120 minutes)
0 to 30	Very suitable	Very suitable	Suitable	Suitable	Suitable.
30 to 60	Very suitable	Suitable	Suitable	Unsuitable	Unsuitable.
60 to 130	Suitable	Suitable	Unsuitable	Unsuitable	Very unsuitable.
130 to 200	Suitable	Unsuitable	Unsuitable	Very unsuitable	Very unsuitable.
Over 200	Very unsuitable	Very unsuitable	Very unsuitable	Very unsuitable	Very unsuitable.

suitable, other factors usually determine the final choice of equipment.

3.1.3 PHYSICS

(1) The physics applicable to self-contained diving is basically the physics of pressure, gases, and fluids. Part 1 covers the basic physics of diving. Study and understand that section thoroughly.

(2) The use of scuba accentuates certain aspects of physics, primarily specific applications of the general gas law, but also hydrostatics and fluid dynamics.

General Gas Law

(3) The general gas law relates pressure, volume, and temperature in a mass of gas. Its common expression is an equation for the initial and final conditions in the same mass of gas:

$$\frac{(P_1)(V_1)}{(T_1)}=\frac{(P_2)(V_2)}{(T_2)}$$

where

P_1=initial pressure (any absolute units)
V_1=initial volume (any units)
T_1=initial temperature (any absolute units)

and

P_2=final pressure (units identical to P_1)
V_2=final volume (units identical to V_1)
T_2=final temperature (units identical to T_1)

(4) The most frequent error in the use of this equation is failure to use absolute units for pressure or temperature. Before substituting numerical values in the equation, check the following points:

(*a*) When using psi, be sure to add 14.7 to any gage pressure.

(*b*) When using feet, be sure to add 33 to any depth.

(*c*) When using degrees Fahrenheit, be sure to add 460 to the Fahrenheit temperature.

(*d*) When using degrees centigrade, be sure to add 273 to the centigrade temperature.

(*e*) Make sure that the units are the same for both sets of conditions. (Do not use gallons for the initial volume and cubic feet for the final volume, for example.)

(*f*) Barometers give pressure readings in absolute units. Do not add 760 (for millimeters of mercury) or 29.92 (for inches of mercury) to barometer readings.

(5) This law has the following major applications:

(*a*) Determination of cylinder gas capacity from cylinder volume and pressure rating.

(*b*) Determination of mass (expressed as volume at the surface) from actual volume, depth, and temperature.

Other Considerations

(6) Hydrostatics is an important aspect of the physics of self-contained diving. There is always some differential of water pressure between the easy-breathing point in the diver (at the base of his throat) and the location of the breathing bag (or demand regulator, as the case may be). The diver's chest muscles have to work against this differential with every breath. If the differential is too large, either as positive or negative pressure on the lungs, the work of breathing may be intolerable to the diver. Even if the diver does tolerate the pressure differential, damage to the lungs may result.

(7) Fluid dynamics (of gas flow) becomes important for adequate lung ventilation during exertion. During rapid deep breathing, the gas flow in a breathing circuit can reach high peaks. Even at medium depths the gas density may be high. If a demand regulator is not adequate, it may "cut off" during high peak flows. This condition makes the work of breathing rise beyond the diver's ability to continue his exertion. Even with an adequate gas supply (such as a large, well-positioned breathing bag), certain factors such as small breathing tubes, complicated check valves, and other design features may restrict the gas flow excessively.

3.1.4 PHYSIOLOGY

(1) The physiological considerations which arise in diving result primarily from the effects of exposure to pressure higher than normal, and secondarily from the effects of breathing various gases. At any given depth with any specific breathing medium, the self-contained diver encounters exactly the same primary and secondary effects of pressure as does the surface-supplied diver. Any other man breathing the same gas at the equivalent pressure experiences the same effects. Although the diver is surrounded by water instead of gas, a situation which raises the physical problem of furnishing him with

something to breathe, this water environment seldom creates any greater physiological problems than does swimming.

(2) The basic physiology of self-contained diving is identical to the basic physiology of pressure given in part 1. Study and understand that section before reading the next article of this section. Certain medical problems of diving become more prominent in scuba diving, but they all stem from the basic physiology of pressure.

3.1.5 MEDICAL PROBLEMS

(1) Men engaged in self-contained diving are subject to practically all the hazards of surface-supplied diving plus those of swimmers generally, as well as other hazards peculiar to the type of scuba used. All divers must know these possible hazards, recognize them when they occur, and calmly carry out the recommended procedures.

(2) In addition to the general diving problems, the self-contained diver must know the medical problems peculiar to or accentuated by the use of scuba. The following is a discussion of these problems, grouped according to the various situations in which a diver may find himself.

Drowning

(3) Drowning is the most frequent cause of death in self-contained diving. Of the many causes of drowning, the most common is physical exhaustion resulting from swimming after surfacing. Other common causes are exhaustion of gas supply, entanglement, flooding of the apparatus, and panic due to the loss of mask or mouthpiece. Drowning will frequently hide the diving accident which caused it.

Treatment

(4) Give the mouth-to-mouth method of artificial respiration immediately (app. A). Use a resuscitator if available, but do not wait for one. Every diver should be well acquainted with these methods of treatment, and be proficient in their use.

(5) The best preventive measures to avoid drowning are: (a) thorough training in emergency procedures, (b) ability to swim well, and (c) avoidance of panic.

Air Embolism

(6) Part 1 gives a detailed discussion of air embolism. This accident is probably the second most common cause of scuba fatalities; only drowning is more common. When a man loses his air supply while under water he has an overwhelming instinct to hold his breath and surface immediately. The lack of adequate exhalation during a panicky ascent creates excessive pressure in the lungs. This condition has produced air embolism in less than 15 feet of water. Increased lung pressure may also occur in a normal ascent if the diver fails to breathe continuously.

(7) Air embolism may occur without any warning of increased pressure in the chest during what appears to be a normal ascent from depth. Symptoms and signs usually appear during ascent or within 1 or 2 minutes after surfacing. *Give immediate recompression treatment.*

(8) Air embolism is a grave condition. Treat it as a serious case. Follow the treatment outlined in part 1. Treatment must be immediate. A delay of 1 or 2 minutes may mean loss of the diver's life. Facilities for treatment of casualties should be immediately available at scuba training facilities, where a higher incidence of air embolism may occur.

(9) Prevent air embolism by thorough training in scuba. Learn to avoid hazardous situations and to handle emergencies without panic when they do happen. Breathe continuously during ascent from depth so that overpressurization of the lungs will not occur. If it is necessary to make an emergency ascent to the surface because of loss of air supply, swim to the surface (3.8.1(4)). Because a recompression chamber may not be immediately available for treatment of air embolism occurring during scuba operations, it is of the utmost importance to prevent this accident.

Overexertion

(10) The scuba diver may frequently have to work very hard. On occasions a few moments of extreme activity may mean the difference between life and death. Even with minimal breathing resistance, scuba will hamper respiration to some degree.

(11) Muscular exercise increases the breathing rate. Overexertion eventually increases the

breathing rate enough to cause a sensation of inadequate lung ventilation. This sensation can occur even with free access to air and it is unpleasant even under ideal conditions. If the scuba restricts the diver's breathing, the sensation occurs more readily and also becomes terrifying.

(12) The breathing response to a burst of activity may not occur immediately. If the response is delayed, it does not adequately warn a man that he is exceeding his powers. When the response finally does occur, the diver must stop working and pant for several minutes.

(13) A rest period is the most satisfactory way to relieve the condition. If complete rest is not allowable, slacken the work rate as much as possible. Remember that overexertion can readily make breathing difficult, and that muscular fatigue may not occur before shortness of breath occurs. Untrained men, especially inefficient swimmers, tend to panic under these conditions and try to surface. *Do not panic!*

(14) Know the limits of your own ability to breathe, and know how restrictive your scuba may be during hard work. Avoid overexertion. When you must work extremely hard in an emergency, be prepared for shortness of breath.

Bends

(15) Part 1 has a complete discussion of bends. Scuba divers can develop bends when air in open-circuit apparatus and gas mixtures in semi-closed-circuit apparatus are used. Divers do not have this problem when oxygen in closed-circuit apparatus is used, because the inert gas partial pressure is too low to cause saturation of tissues. Greater no-decompression depths and times are possible with gas mixtures containing more than 20 percent oxygen. The nitrogen breathed from such mixtures is considerably less than the nitrogen contained in air.

(16) Symptoms of bends are the same for self-contained diving and surface-supplied diving.

(17) Upon experiencing any unusual sensations, such as pain, twinging numbness, or nervous system disturbances, report at once to a medical or diving officer. Treat bends by recompression in accordance with the U.S. Navy Treatment Tables (table 1–30 and table 1–31).

(18) To prevent bends in self-contained diving, strictly observe the decompression tables. Stay within the no-decompression limits when a recompression chamber is not immediately available. With a recompression chamber available, give adequate decompression stops for the dive, using the Navy Standard Decompression Tables. When making repetitive or multilevel dives, adhere to the decompression procedure outlined in part 1.

(19) In addition, select diving personnel carefully (good physical condition), evaluate each man before a dive, give care to details of the dive, and incorporate safety factors in all strenuous dives, just as in surface-supplied diving.

Nitrogen Narcosis

(20) It is often incorrectly assumed that nitrogen narcosis is not a great problem in self-contained diving. Actually, nitrogen narcosis is as great a hazard in self-contained air and mixed-gas diving as it is in deep surface-supplied diving. Considerations of nitrogen narcosis, air supply duration, and decompression make 130 feet the maximum satisfactory depth for self-contained diving while using air. However, the practical limit for self-contained diving while using air is in most instances 60 feet. Relatively few dives deeper than this are made, and so nitrogen narcosis may not often be encountered. Nevertheless, at depths beyond 100 feet, nitrogen narcosis may develop in air scuba.

(21) The loss of judgment and skill, and the "drunkenness" characteristic of nitrogen narcosis, have been fully appreciated as hazards to the safety of the surface-supplied diver. He, however, has the advantage of continuous communication with the surface. The diver's tenders can assess his condition and give him specific instructions for handling the situation. If conditions require, the tenders can haul the diver up. The self-contained diver has no such safeguards. His life is entirely in his own hands, and the number of fatal mistakes he can make under nitrogen narcosis is limited to one.

(22) The scuba diver who expects to do deep diving using air should become acquainted with his own response to nitrogen narcosis by exposure in a recompression chamber. He should not overestimate his tolerance for nitrogen narcosis, and he must not consider resistance to nitrogen narcosis as being equivalent to immunity.

Fatigue, exertion, and carbon dioxide buildup increase a diver's susceptibility to nitrogen narcosis.

(23) There is no treatment for nitrogen narcosis. The effect diminishes as the diver leaves the diving depth, and vanishes before he reaches the surface.

(24) There is no prevention for nitrogen narcosis if air is being breathed, except by avoiding deep dives. If it is necessary to make a deep dive, the diver may lessen the effects of nitrogen narcosis by exerting strong willpower and self-control, and by slowing down his activity and work rate.

Carbon Monoxide Poisoning

(25) The only common cause of carbon monoxide poisoning in self-contained diving is contaminated compressed air. It occurs almost exclusively in open-circuit scuba, although theoretically it can occur in semi-closed-circuit scuba if air is the basis of the nitrogen-oxygen mixture.

(26) The diver may not develop symptoms until he approaches the surface. A diver must be sure to look for the signs of carbon monoxide poisoning if his buddy becomes disoriented or unconscious, especially during ascent.

(27) Bring the victim to the surface and give him fresh air. Get him out of the water if possible, and give him oxygen to breathe. If he is not breathing, give him artificial respiration. Use an oxygen resuscitator if available. If the diver is in serious condition, use treatment table 5 or 6 (tables 1–30 and 1–31).

(28) To prevent carbon monoxide poisoning, insure the purity of the breathing gas. Keep the compressor air intakes away from engine exhausts. Analyze the breathing air periodically for carbon monoxide. The maximum allowable concentration of carbon monoxide in compressed air for scuba use is 20 parts per million (0.002 percent).

Oxygen Poisoning

(29) Oxygen poisoning is a serious possibility in self-contained diving whenever a high partial pressure of oxygen exists. Such partial pressures occur in many situations, and the risk of oxygen poisoning is not confined to the use of closed-circuit oxygen rebreathing apparatus. Oxygen limits are a major consideration in the use of mixed gas (including helium mixtures), and oxygen poisoning is at least theoretically possible with open-circuit air scuba at depths beyond 225 feet.

(30) Know the symptoms of oxygen poisoning. Never depend on minor symptoms for a warning of excessive exposure, because many victims go into convulsions without prior warning.

(31) Upon noticing any early-warning symptoms of oxygen poisoning, take immediate steps to lower the oxygen partial pressure. The most practical step is to ascend to a lesser depth. If possible, break the surface and start breathing air. If the situation requires completion of the work, breathe air at least 5 minutes before returning to depth.

(32) The role of the buddy may be difficult if a diver develops convulsions under water. The danger of drowning far outweighs the hazard of air embolism. Take the victim to the surface immediately, preferably feet first. When on the surface, inflate the victim's lifejacket and keep his face out of the water. Signal for help and stay with the victim until help arrives. If he has not injured himself during the convulsion or developed an embolism during ascent, the victim will usually revive after a few minutes. However, he may become semiconscious periodically for an hour or more. Do not leave him until he receives competent medical care.

(33) Because oxygen convulsions in self-contained diving could easily result in drowning, always stay within the depth-time limits given in part 1 for breathing pure oxygen. When pure oxygen is used, a small error in depth measurement can make a large difference in the safe exposure time. If there is any doubt of the diving depth, use the shorter time limit for a greater depth.

(34) Exertion and carbon dioxide excess can accelerate the onset of oxygen poisoning. To help prevent carbon dioxide accumulation, use fresh, efficient carbon dioxide absorbent in the canister and insure that no leaks into the breathing circuit exist.

(35) It is important that scuba divers who may breathe high partial pressures of oxygen pass an oxygen-tolerance test satisfactorily.

Carbon Dioxide Excess

(36) Carbon dioxide excess may occur with scuba for a number of reasons. The most common cause is carbon dioxide accumulation in the breathing system of closed-circuit or semi-closed-circuit apparatus. This occurs if the absorption system fails, or if the diver exceeds the capacity of the absorption system by overexertion.

(37) Accumulation of carbon dioxide in the breathing bag may be gradual. The usual symptoms are increased breathing, lightheadedness, sleepiness, dizziness, faintness, blurring of vision, and difficulty in hearing. However, in certain instances rapid increase of carbon dioxide may cause the diver to lose consciousness without his becoming aware of these usual warning symptoms.

(38) Treatment for carbon dioxide excess is simple, provided that there is no such complication as drowning. If the buddy develops symptoms at depth, flush his breathing bag to wash out any retained carbon dioxide. Bring him to the surface and let him breathe air. Exposure to fresh air is all that is required if the victim is still breathing. If he is not breathing, give him artificial respiration and administer oxygen. The aftereffects in uncomplicated cases rarely include more than headache, nausea, and fatigue.

(39) Prevention of carbon dioxide excess in breathing apparatus is very important because the symptoms may not be distinct enough to serve as reliable warnings. Pay careful attention to the filling and sealing of absorption canisters.

(40) Watch for divers who do not respond to a high level of carbon dioxide. Give these men thorough instruction in recognizing the less obvious symptoms of carbon dioxide excess. Always try to pair such men with divers who have good response to a high level of carbon dioxide.

Oxygen Deficiency

(41) The cause of oxygen deficiency in self-contained diving is a low level of oxygen in the breathing medium.

(*a*) In open-circuit scuba, no problem exists as long as the breathing medium is air.

(*b*) In closed-circuit scuba, oxygen deficiency may occur because the system was not properly purged, or because the supply gas is not pure oxygen.

(*c*) In semi-closed-circuit scuba, oxygen deficiency is a considerable hazard. The supply contains inert gas, and a failure of the injector system can easily allow the oxygen to fall to a critically low value.

(42) Oxygen percentage can be dangerously low at depths greater than 10 feet without producing symptoms of oxygen deficiency. As depth increases, the oxygen percentage can decrease without producing symptoms. However, at some point during ascent with such a low oxygen percentage, the diver will develop oxygen deficiency. The conditions will become increasingly severe as he approaches the surface. Following loss of consciousness, the victim may stop breathing and die if he does not have adequate oxygen very quickly.

(43) Be aware of the possibility of oxygen deficiency and know the symptoms. Watch your buddy for these symptoms if oxygen deficiency is possible with his scuba. Carry out treatment promptly if he develops oxygen deficiency.

(44) While he is under water, give the victim more oxygen in his breathing medium. In closed-circuit scuba, flush his bag with oxygen. In semi-closed-circuit scuba, flush his bag with mixed gas and continue to flush it periodically. The victim will recover rapidly if he is still breathing.

(45) If the victim is not breathing, get him out of the water, remove his scuba, and start artificial respiration immediately. Use an oxygen resuscitator if available.

(46) To minimize the hazard of oxygen deficiency, give careful maintenance and proper use to any equipment in which it can occur.

Other Considerations

(47) Part 1 and appendix A contain more detailed discussions of the following conditions. They are also discussed briefly here because of their common occurrence in scuba diving.

(48) Upper respiratory infections are common because of frequent fatigue and exposure to the elements. They are important because they produce a high incidence of ear and sinus squeeze. Exposure and swimming should be forbidden until any infection has cleared up.

(49) External ear-canal infections frequently occur in swimmers, especially in the warmer climates. The infections are disabling and resistant to treatment. Do not dive with the ear canals exposed to water until canals have adequately healed.

(50) Eardrum rupture may allow cold water to enter the middle ear. Cold water in the middle ear causes severe dizziness, nausea, and vomiting. Be aware of these possibilities and do not panic. The symptoms pass as soon as the water warms to body temperature. Stabilize yourself by holding on to your buddy, the descending line, or any other object at hand. The symptoms are of short duration. After the condition passes, surface at once. Do not dive again until the eardrum has completely healed.

(51) Sunburn can be disabling both because of the pain itself, and because of the toxic symptoms which accompany burns of even moderate severity and extent. During operations conducted in areas where exposure can result in severe sunburn, take precautions to expose personnel gradually. Use diving underwear or other covering to provide protection against exposure to sun. Ointments of 10 percent para-aminobenzoic acid in petrolatum are highly effective for preventing sunburn, even if the diver is continually in and out of the water.

(52) Motion sickness can limit the satisfactory performance of a scuba diver. Scuba divers should have a highly developed adaptability to motion, because they have to spend a great deal of time in small craft. Divers susceptible to motion sickness to any extent should be kept out of scuba operations. Drugs such as Dramamine, Bonamine, and Marezine can combat this condition effectively if they do not produce side effects which reduce personnel efficiency.

(53) Water temperature of 80° F and lower can chill even an active swimmer. Cold water is the most limiting factor in operations. Part 1 gives a full discussion on the subject of protection against cold. The immediate effect of cold on the scuba diver is to increase his oxygen consumption and lung ventilation. The increased work of breathing produces fatigue and increases gas consumption. Once the chilled diver is out of the water, warm him immediately and give him hot liquids, if practical.

3.1.6 SELECTION OF PERSONNEL

General

(1) The candidate for training as a scuba diver must be a volunteer. Many men do not have the mental attitude necessary to undergo training in scuba diving. An involuntary trainee might be a constant hazard to himself and to his buddy. The candidate for training must want to enter this adventurous field, and want to cope with the characteristic conditions of scuba diving.

(2) In the selection of personnel, outward appearances are frequently deceiving. A muscular, calm trainee may break under strain of scuba diving, compared to a spindly, nervous trainee who may prove to be the best scuba diver in the class. If a volunteer qualifies physically and psychologically, give him a fair training trial before rejecting him, whatever the initial appearances may be.

Physical Requirements

(3) Self-contained apparatus sometimes makes severe demands on the body. It may subject the scuba diver to the effect of a high carbon dioxide rate or to the danger of oxygen poisoning. It can greatly tax his ability to breathe when he has to maintain a high level of exertion. To teach the scuba diver to meet every contingency, his training is rigorous. For these reasons, the candidate must be in excellent physical condition.

(4) Chapter 15, article 30, of the Manual of the Medical Department specifies the physical qualifications for all divers (app. F).

Psychological Requirements

(5) The scuba diver is master of his own destiny. He must be self-reliant, for he is alone except for his buddy. Any other assistance is remote and communication is poor.

(6) The scuba diver must be steady nerved. He has to work calmly in darkness and isolation, even in the presence of known hazards, yet he must have normal fear reactions and a healthy respect for danger.

(7) The scuba diver must be flexible. He carries out orders conscientiously and can still think for himself. He is well informed about an

operation as a whole without stressing his own role in it. He is a good team worker, but he is equally capable of working alone.

(8) Chapter 15, article 30, of the Manual of the Medical Department specifies the psychological qualifications for all divers.

Other Requirements

(9) The scuba diver has to be mechanically minded. He occasionally uses ingenuity to keep his breathing apparatus operative. He frequently tackles difficult jobs with inadequate tools. He must always understand the operation, use, and care of his equipment.

(10) The scuba diver must be a good swimmer. On routine jobs he will often have to cover several hundred yards under water. In an emergency he may have to abandon his breathing apparatus and swim on the surface to some distant point.

(11) Article C–7408 of the Bureau of Personnel Manual specifies the prerequisite qualifications for scuba diving candidates (app. F).

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SECTION 3.2 TECHNIQUES

3.2.1 PERSONNEL

The Diving Supervisor

(1) The diving supervisor is the man in immediate charge of diving operations. He is either the diving officer or his specified representative.

(2) The diving supervisor has complete authority and full responsibility in the conduct of operations. All divers are in turn responsible to the diving supervisor for carrying out their assigned missions as completely as possible according to the preliminary planning and briefing.

(3) Under normal conditions the diving supervisor does not enter the water. His usual post is on the surface. Whenever possible, he has a full surface crew under his command and he does not have any of the routine duties of a tender or a timekeeper.

(4) As a diving supervisor, observe the following:

(*a*) Plan the operation as completely as possible.

(*b*) Brief the divers as fully as possible.

(*c*) Take all proper precautions against foreseeable contingencies.

(*d*) Supervise and direct all phases of the diving operations.

(*e*) When working with an optimum surface crew, do not personally enter into any phase of an operation except to make the predive and postdive inspections, to give directions, or to handle an emergency.

The Surface Crew

(5) The optimum surface crew (fig. 3–2) should include the following:

(*a*) One tender for every surface-tended diver.

(*b*) One tender for every buddy pair.

(*c*) One timekeeper with no other duties.

(*d*) One standby diver.

(6) The minimum surface crew must include the following:

(*a*) One tender-timekeeper for every lone surface-tended diver.

(*b*) One tender-timekeeper for all buddy pairs operating in one vicinity.

(*c*) One standby diver for all lone surface-tended divers.

The Diver

(7) The diver is the man closest to the job. He has the responsibility of carrying out to the best of his ability the task assigned to him. He must exercise full judgment in doing so. He may use his own discretion in performing any phase of his mission, but he must immediately obey a signal to surface.

(8) As a diver, observe the following rules:

(*a*) Understand the briefing completely.

(*b*) Complete the assigned task.

(*c*) Promptly obey a signal to surface.

The Tender

(9) The tender should be a qualified scuba diver or diving supervisor. He must know standard diving signals thoroughly. He must not have any additional duties while tending, except those duties as timekeeper in the minimum surface crew.

(10) The tender has the primary responsibility for the safety of the line-tended scuba diver. Observe the following rules when tending a diver:

(*a*) Keep slack out of the line.

(*b*) Signal the diver frequently. Be sure that he answers.

(*c*) Be aware of the diver's location at all times by watching the diver's bubbles.

(*d*) Be alert for emergencies.

(*e*) Immediately check a surfaced diver to determine if he needs help.

FIGURE 3-2.—Tender, timekeeper, and standby diver.

The Timekeeper

(11) Whenever possible, the timekeeper should have no other duties. His main job is to keep stopwatch time on the diver or divers assigned to him. The timekeeper should observe the following rules:

(*a*) Log the time of starting descent.

(*b*) Know the probable diving depth.

(*c*) Know the probable duration of the apparatus.

(*d*) Notify the supervisor when the diver's bottom time is up.

(*e*) Foresee decompression and warn the diving supervisor soon enough to make adequate arrangements.

(*f*) Give the diving supervisor the proper decompression schedule.

(*g*) Log the time of starting ascent and the beginning and end of decompression stops (when these times are known).

(*h*) Log the time of surfacing.

3.2.2 THE BUDDY SYSTEM

(1) The buddy system is the biggest single safety factor in scuba diving. It makes two divers responsible for each other's safety over and above all other safety precautions which the diving supervisor may take. Use the buddy system whenever possible in any diving operation, even for surface-tended scuba divers.

The Buddies

(2) The buddies are a pair of scuba divers working as a unit (fig. 3-3). Each of the pair is responsible for his buddy's safety through-

FIGURE 3-3.—The buddy pair.

out the dive. Both are jointly responsible for completion of the mission assigned. The buddies are also jointly responsible for closely observing depth and time, and for taking decompression stops when required.

The System

(3) Maintain continuous contact with your buddy. Where visibility is good, keep him in sight at short range. Where visibility is poor, use a short buddy line to link each to the other.

(4) Know standard diving signals and any other special signals. Watch for any signal from your buddy. Acknowledge it promptly.

(5) Be alert to help your buddy. If he shows any sign of distress, whether he signals or not, go to him at once. Find out what the trouble is and take action as necessary.

(6) Never separate from your buddy unless he is hopelessly entangled and you must leave him in order to get help.

Visual Signals

(7) The standard diving signals listed in part 1 apply to all diving. Visual signals are needed primarily by scuba divers. Use the following signs for visual signaling:

(*a*) "Hold everything!" Clench a fist, with the thumb extending across the index and middle fingers (fig. 3-4).

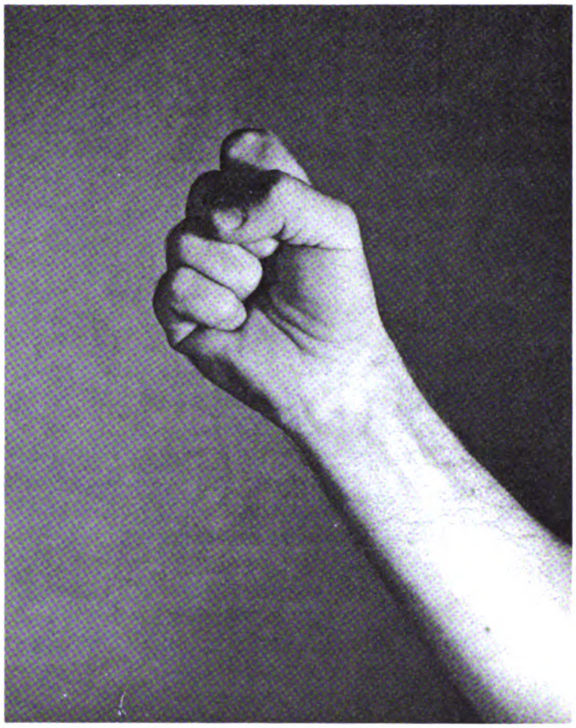

FIGURE 3-4.—"Hold everything."

(*b*) "I am having trouble with ———." Point with the index finger (fig. 3-5) to the location of the trouble (ear, sinus, mouthpiece, regulator, cylinder, reserve valve, and so on). In the case of squeeze, this sign is merely informative. However, if the trouble involves

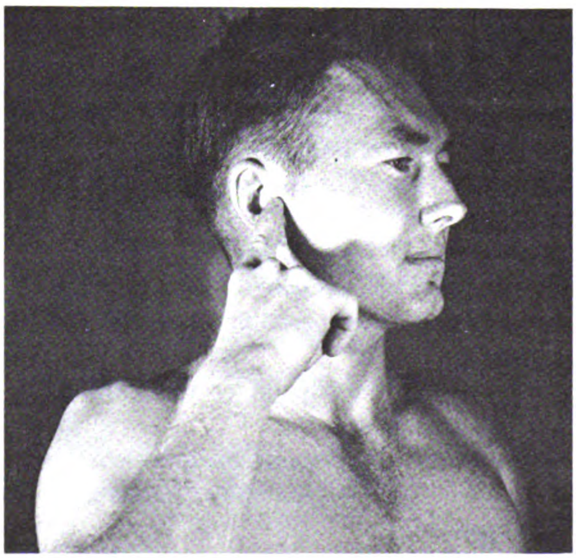

FIGURE 3-5.—"I am having trouble with my ear."

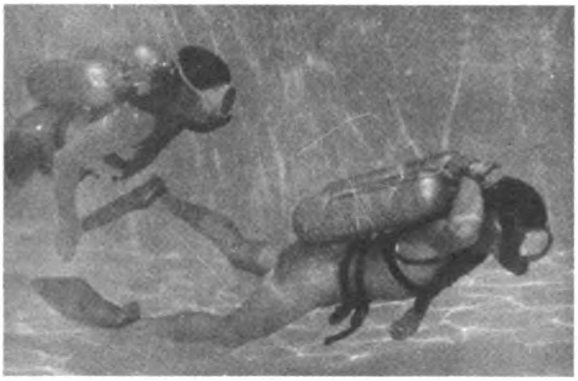

FIGURE 3-6.—"I am having trouble with my air."

equipment, the buddy must investigate immediately and take the necessary corrective action. For instance, if the diver points to his scuba manifold, he may be out of gas (fig. 3-6). Check that his cylinder stop valves are open and then open his reserve valve.

(*c*) "All right?" or "All right." Touch tip of the thumb to the tip of the index finger. Extend the other three fingers, holding them together (fig. 3-7).

(*d*) "Let's go up, down, right, or left." Close the hand and extend the thumb. Point with the thumb in the desired direction (fig. 3-8).

(*e*) "Pick me up." Hold one hand out of the water, fingers together and straight, palm to-

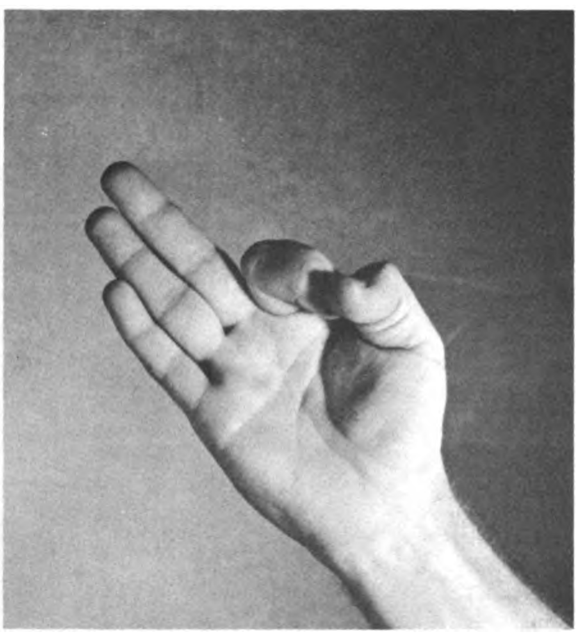

FIGURE 3-7.—"All right."

FIGURE 3-8.—"Let's go up."

ward the pickup boat (fig. 3-9). Do *not* wave hand.

(*f*) "Pick me up NOW." (Emergency signal.) Wave one or both hands overhead (fig. 3-10).

(8) The ability to convey numerical information clearly and rapidly may be essential to the

FIGURE 3-9.—"Pick me up."

FIGURE 3-10.—"Pick me up now."

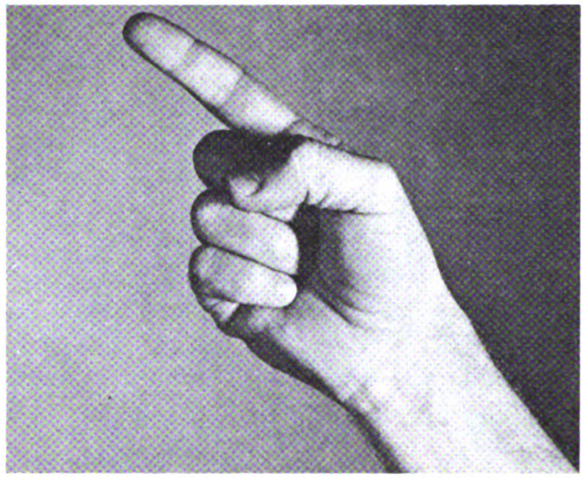

FIGURE 3-12.—Sign for 1.

scuba diver. The following signs are the digits from 0 through 9:

(*a*) *Zero* (*0*).—Bend all the fingers into a half circle, holding them together. Complete the circle by touching the tip of the thumb to the tips of the middle and index fingers (fig. 3-11).

(*b*) *One* (*1*).—Extend the index finger. Fold the other three fingers lightly into the palm and lay the thumb across the middle finger (fig. 3-12).

(*c*) *Two* (*2*).—Extend the index and middle fingers, separating them slightly. Fold the other two fingers lightly into the palm and lay the thumb across the ring finger (fig. 3-13).

(*d*) *Three* (*3*).—Extend the index and middle fingers and the thumb, separating them slightly. Fold the other two fingers down at the knuckle (fig. 3-14).

(*e*) *Four* (*4*).—Extend all four fingers, separating them slightly. Lay the thumb across the palm to touch the base of the little finger (fig. 3-15).

(*f*) *Five* (*5*).—Extend all four fingers and the thumb, separating them slightly (fig. 3-16).

(*g*) *Six* (*6*).—Hold the nail of the little finger with the thumb. Extend the other fingers, separating them slightly (fig. 3-17).

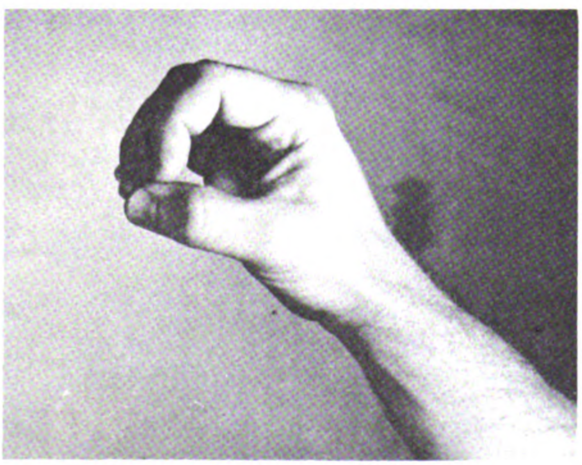

FIGURE 3-11.—Sign for 0.

FIGURE 3-13.—Sign for 2.

FIGURE 3–14.—Sign for 3.

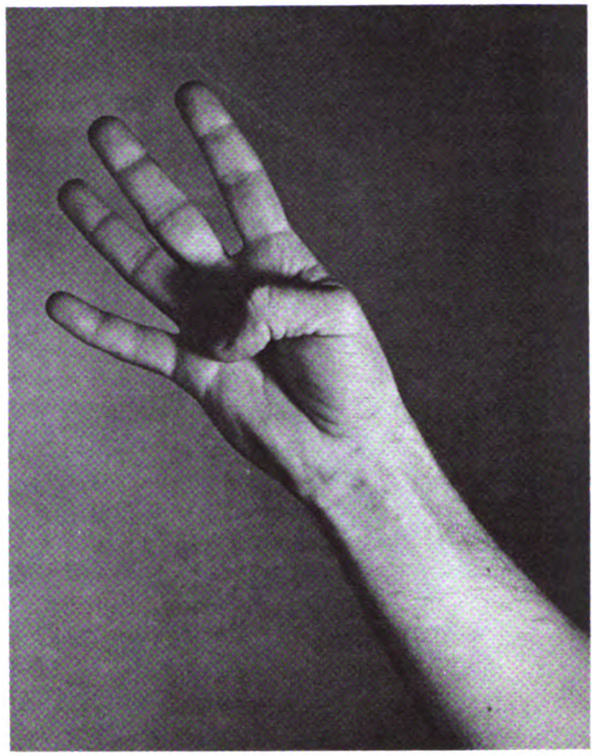

FIGURE 3–15.—Sign for 4.

(*h*) *Seven* (*7*).—Hold the nail of the ring finger with the thumb. Extend the other fingers, separating them slightly (fig. 3–18).

(*i*) *Eight* (*8*).—Hold the nail of the middle finger with the thumb. Extend the other fingers, separating them slightly (fig. 3–19).

(*j*) *Nine* (*9*).—Hold the nail of the index finger with the thumb. Extend the other fingers, separating them slightly (fig. 3–20).

(9) To indicate a number larger than 9, give the individual digits of the number in the order that you would write them from left to right. For example, to say "The time is 1435," tap your wrist and then give the signs for 1, 4, 3, and 5, in that order.

(10) Make the number signs slowly and distinctly. Throw each sign out emphatically and hold it until the buddy returns the signal. Hold the hand slightly away from the body. When the buddy answers the sign, pull the forearm back toward the shoulder before making the next sign. Change the sign as the forearm snaps away again. To end one number and start another, clench the fist after the last digit of the first number.

(11) Certain other signs are valuable for conveying basic information.

(*a*) "How deep?" or "Depth ____ feet." Extend one arm to the side, holding the hand palm down. Swing the forearm horizontally back and forth about 60 degrees (fig. 3–21).

(*b*) "What direction?" or "Compass course ____ (degrees)." Close the hand and extend the thumb. Twist the hand about the wrist to the right and left several times (fig. 3–22). When signaling the compass course, always give it as a three-digit number. For example, to say "Compass course 045," make the sign for compass course followed by the digits 0, 4, and 5, in that order.

(*c*) "What time?" or "The time is ____." Crook the index finger of one hand and tap it several times on the back of the other hand at the wrist (fig. 3–23). When signaling the time of day, always give it as a four-digit number

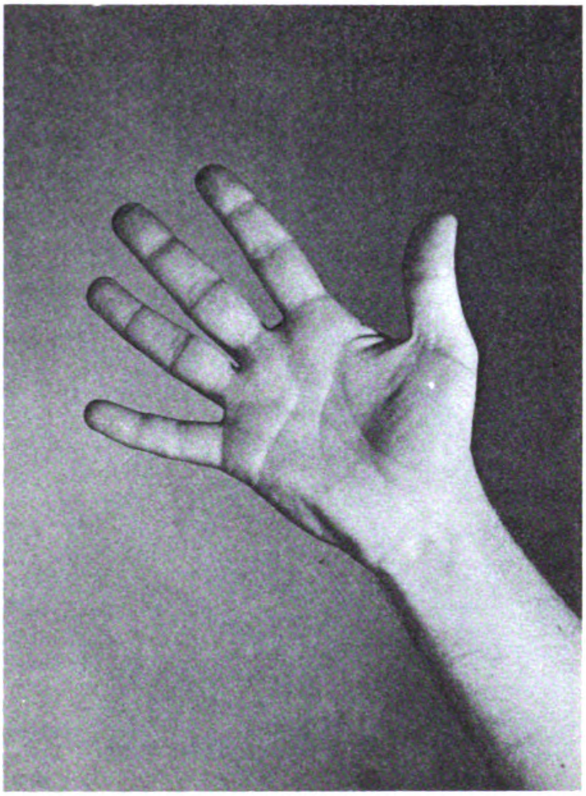

FIGURE 3–16.—Sign for 5.

FIGURE 3–17.—Sign for 6.

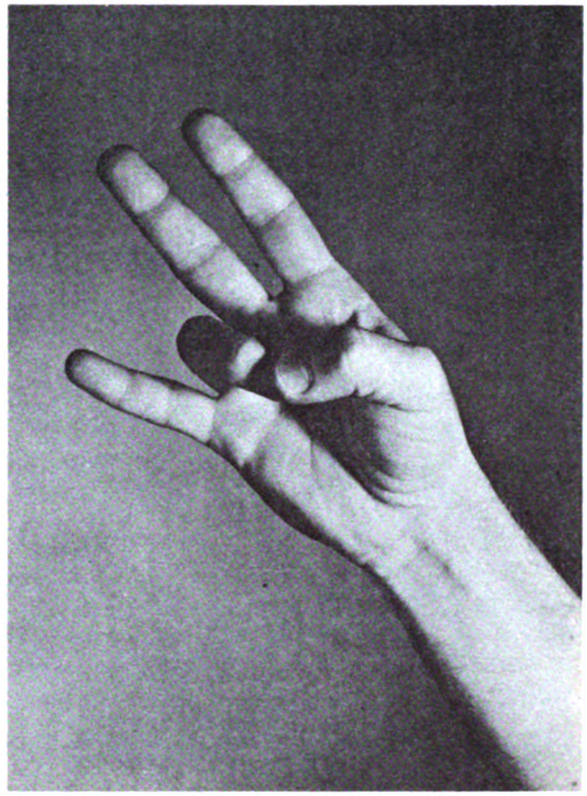

FIGURE 3–18.—Sign for 7.

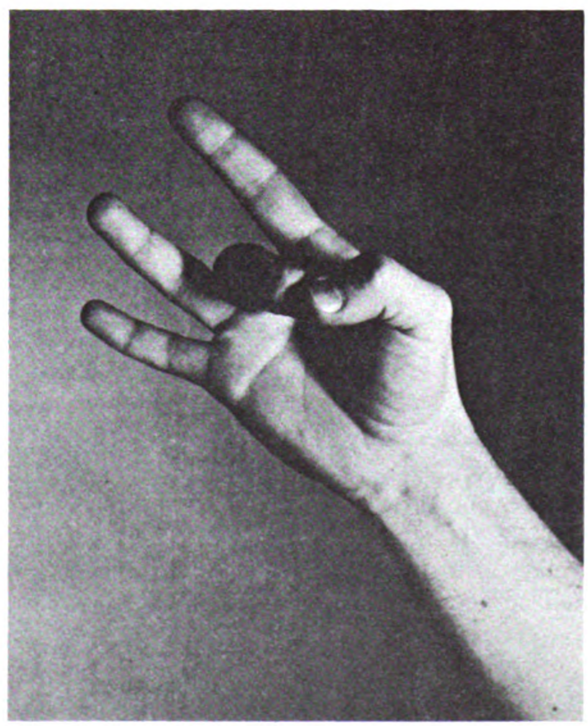

FIGURE 3–19.—Sign for 8.

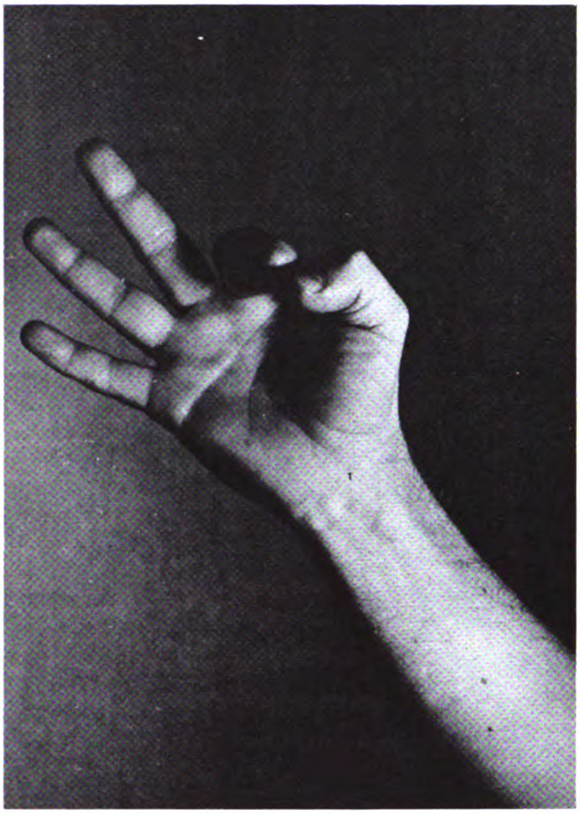

FIGURE 3–20.—Sign for 9.

(0930, 1145, 1415, etc.). See the example in paragraph (9).

(12) Be forehanded. Mentally review the possible emergencies for self-contained diving and for the scuba in use and line up a course of action for each emergency.

(13) Be calm. When an emergency breaks, follow the emergency procedure as quickly and as coolly as possible.

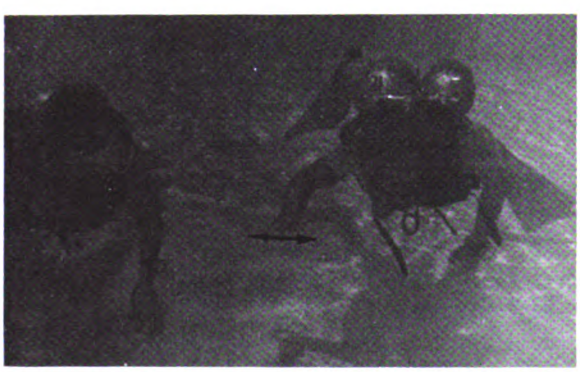

FIGURE 3–21.—"How deep?"

FIGURE 3–22.—"What direction?"

Surface-Tended Divers

(14) Use the buddy system even for surface-tended divers if at all possible. When the situation dictates that a single diver must make a surface-tended dive without a buddy, adhere to the following rules (fig. 3–24):

(*a*) Secure the tending line around some part of the diver's body (the waist is best).

(*b*) Secure the tending line under all the diver's releasable equipment. Secure the line to

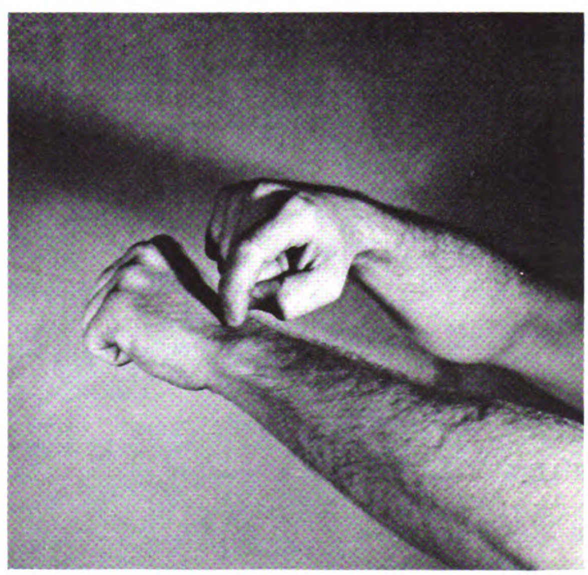

FIGURE 3–23.—"What time?"

FIGURE 3–24.—Scuba diver rigged for surface tending.

itself. Do not secure it to any of the diver's equipment.

(*c*) Use only a qualified diver as tender.

(*d*) Be sure that both diver and tender thoroughly know all standard and special diving signals.

(*e*) Instruct the scuba diver to use extreme caution and to give careful thought to each step before taking it.

Standby Diver

(15) The diving supervisor should have a standby diver at every diving operation. He must have a standby diver for a surface-tended diver without a buddy. Observe the following rules for the standby diver:

(*a*) Wear all minimum equipment except the scuba.

(*b*) Wear all necessary additional accessories.

(*c*) Have the scuba fully ready for instant use. Wear it if convenient.

(*d*) At the least sign of trouble, put on the scuba and be ready for immediate descent.

(16) Because the standby diver dives only in an emergency, he is an exception to the general requirement for using the buddy system. However, when standing by for a surface-tended diver without a buddy, the standby diver should also wear a line.

3.2.3 PRELIMINARY PLANNING

(1) Preliminary planning is vital for a successful dive. Without adequate preliminary planning, the entire operation may fail, and can seriously endanger the lives of the divers involved. The diving supervisor has the responsibility for adequate preliminary planning, but the diving team should assist him as much as possible, especially in technical matters.

(2) The planning phase of a diving operation is broken into several steps.

(*a*) Survey of the problem.

(*b*) Choice of diving techniques.

(*c*) Selection of equipment.

(*d*) Fulfillment of safety precautions.

(*e*) Briefing the diving team.

(*f*) Setting up the operation.

Survey of the Problem

(3) Study all aspects of the job to be done. Frame the entire problem in writing and state the objectives clearly. Select an approach to the problem.

Choice of Diving Techniques

(4) Consider the requirements to solve the problem: range, depth control, portability, protection, communication, decompression, and similar needs. Decide whether to use self-contained or surface-supplied diving techniques.

(5) Conditions in the operating area are important in making a choice. Safety in self-contained diving depends in large part upon environmental conditions, and upon the suitability of arrangements made for diving under these conditions. Listed below are some of the undesirable conditions which divers may meet.

(*a*) For underwater visibility, dark or murky water is a disadvantage in all underwater operations. Use either surface-supplied apparatus or self-contained apparatus with surface-supplied techniques. Use lifelines or shorter buddy lines as necessary.

(*b*) In tides and current, even with swim fins, the diver finds it hard to maintain position or to make progress against tides and currents over 1 knot. Use surface-supplied equipment if possible. If self-contained diving is mandatory, use weights and lifeline with the scuba.

(*c*) To adjust to water temperature, the diver needs adequate protective clothing for cold water. A protective suit may limit freedom of movement. It frequently makes buoyancy control difficult. Cold water reduces swimming efficiency and use of hands for work. Surface-supplied equipment may give better protection.

(*d*) While working in contaminated water, the diver must realize that most rivers and harbors are heavily polluted. In such circumstances the heavy surface-supplied equipment is better. If scuba is necessary, use a coverall suit and a full face mask if available.

(*e*) When coping with surface conditions in an emergency, even the best conditions are not favorable if the diver must cover any distance before reaching safety. They become very unfavorable in rough water, heavy surf, or strong currents. Do not dive under such conditions except as necessity dictates.

(6) Decompression is a big factor in choice of techniques. If the actual diving depth and probable working time require decompression, surface-supplied equipment is preferable. When decompression is probable and self-contained diving is mandatory, be sure to make all foreseeable provisions for adequate decompression (3.2.5).

Selection of Equipment

(7) For most self-contained diving operations, open-circuit scuba is entirely satisfactory. Where military considerations dictate, the diving supervisor may select closed-circuit or semi-closed-circuit equipment. Whichever apparatus is in use, the diver must be sure to observe the particular limitations which the equipment imposes on the dive. The following are especially important:

(*a*) With open-circuit scuba there is a rapid reduction of duration with depth, as well as an increase of decompression and nitrogen narcosis problems with depth.

(*b*) With closed-circuit scuba there are very restricted depth limits. There is also a severe hazard of oxygen poisoning and a moderate hazard of carbon dioxide excess.

(*c*) With semi-closed-circuit scuba there is a moderate reduction of duration with depth, a moderate hazard of oxygen poisoning, and a moderate hazard of carbon dioxide excess.

Check of Safety Precautions

(8) After the diving supervisor has surveyed the problem, chosen the technique, and selected the apparatus, he must check applicable safety precautions: general precautions for self-contained diving; specific precautions for the equipment; and special precautions for the operation. Prepare a checkoff list of all pertinent precautions and be sure that they are carried out for the operation.

Briefing the Diving Team

(9) Well in advance of the operation, call the diving team together. Brief the men as thoroughly as possible. Include the following information:

(*a*) Objectives and scope of the operation.

(*b*) Approach to the problem.

(*c*) Conditions in the operating area.

(*d*) Assignment of personnel (buddies, tenders, timekeepers, and assistants).

(*e*) Assignment of missions to individual divers.

(*f*) Schedule of operations.

(*g*) Safety precautions.

(*h*) Special considerations.

Setting Up the Operation

(10) Make a checkoff list of necessary equipment. Consider the following:

(*a*) Available personnel (divers and assistants).

(*b*) Available diving equipment (scuba, compressor, gas, absorbent, and accessories).

(*c*) Available safety equipment (lifejackets, recompression chamber, and resuscitator).

(11) Provide for an adequate base of operations (fig. 3–25). Consider the following:

(*a*) For the immediate base of scuba diving operations, locate a small powercraft as near as possible to the scene. Moor it if possible, preferably to an anchored buoy. Keep the craft free to cast off immediately for recovery of any surfacing diver in trouble at a distance.

(*b*) Where descending lines are in use or lifelines are being tended, provide a second craft for emergency assistance.

(*c*) Enable the diver to enter the water or to return aboard without difficulty. If necessary, provide a ladder or a small stage.

FIGURE 3-25.—Base of operations.

(*d*) Whenever possible, avoid diving directly from shore or large vessels, or from piers or similar installations. The ability to reach a diver directly from a small power craft may save his life.

(12) Determine the location of the nearest recompression chamber. If it is within a reasonable range, provide facilities to transport a casualty there as rapidly as possible. Notify the activity of the proposed diving operation and request that the chamber be ready for treatment.

3.2.4 THE DIVE

Preliminary Preparations

(1) Before the dive, carry out all the preliminary preparations required for the type of scuba to be used.

Minimum Equipment

(2) The minimum equipment for a scuba diver is—

(*a*) Swim trunks.
(*b*) Life preserver.
(*c*) Belt and knife.
(*d*) Swim fins.
(*e*) Face mask.
(*f*) Scuba.

(3) When planning the dive, both the diving supervisor and the diver should consider the diving conditions when deciding what other equipment the scuba diver is to wear. Two highly desirable accessories in any case are a wristwatch and a depth gage.

(4) Other accessories include a weight belt, an exposure suit, a wrist compass, and a buddy line.

Predive Inspection

(5) Before permitting a diver to enter the water, the diving supervisor must make a predive inspection, checking the following:

(*a*) Check that the diver knows each item of the briefing.

(*b*) Check that the diver has completed all the preliminary preparations listed for the type of scuba he is using.

(*c*) Make a predive inspection of the buddy before committing the pair to the water.

Entering the Water

(6) Enter the water feet first by climbing down a ladder or easing over the side. Do not jump in unless the area is known to be free of obstruction and to be of sufficient depth.

(7) Stop at the surface and make the proper surface check for the type of scuba being used.

(*a*) Check your scuba for satisfactory operation.

(*b*) Check your buddy's scuba for leaks of any sort.

(*c*) Check your face mask for proper seal to minimize flooding.

(*d*) Check your buoyancy.

(*e*) Report any inadequacies or malfunction of equipment to the supervisor. Correct any deficiencies before starting the descent.

(8) The diver must be oriented with available natural aids (sunlight, current, and landmarks). If the job requires swimming to a specific point, the diver must check the compass bearing of that point.

(9) When the diver is sure that he and his buddy are ready, he should signal the diving supervisor (and the timekeeper) and start the dive.

Descent

(10) Make a slow, orderly descent. Do not outrun your buddy. Swim down, or pull yourself head first down along the descending line.

(11) Be sure that the pressure is equalizing in the ears and sinuses. Stop the descent if pain develops. Level off or ascend slightly until the pressure equalizes. Discontinue the dive if pressure does not equalize after several tries—never force the issue.

At Diving Depth

(12) Level off at the diving depth, orient yourself, using any available natural aids (sunlight, current, bottom, channel, and so forth). Check with a compass, if available.

(13) Avoid overexertion. Keep activity to a practical minimum. Breathe continuously, as slowly and as deeply as possible. At the first sign of breathlessness, slow down—stop if possible and catch breath before increasing work rate. If fighting a current does not allow a decrease in work rate, break off the dive.

(14) Watch out for entanglement around wreckage, lines, or vegetation. When swimming with poor visibility, keep hands extended ahead.

Free Diving

(15) Wear a comfortable, satisfactory pair of swim fins. Use an efficient kick. Maintain a steady pace geared to the buddy's ability.

(16) Watch the depth and time carefully. Keep the buddy in sight and look at him frequently. Signal to him before any change of direction. Be sure that he understands the signal. Watch that he follows the maneuver.

Line Diving

(17) When using a float line, keep it taut but do not pull the float under the surface. Remember that it can snag objects above the diver; watch for entanglement.

(18) When using any other lifeline, be sure that the tender keeps it taut. Signal him to slacken or tauten as necessary, and communicate with him occasionally by line pulls.

(19) Always remember the risk of entanglement when using a line. Avoid going through small passages or near snags. Keep your knife in mind for emergency disentanglement.

Underwater Tending

(20) When under water and tending a buddy on a line, keep the buddy in sight if possible. If he is out of sight, keep slack out of the line. Signal him frequently and be sure that he answers. Be alert for a distress signal.

Surface Tending

(21) When tending from the surface, keep the diver in view if circumstances permit. Observe the following rules as well:

(*a*) When tending buddies who are using float lines, stay clear, but keep the floats in sight. Watch the floats closely for signals.

(*b*) When tending a diver on a line, keep slack out of the line. Communicate with him often by line pulls.

(*c*) When tending free divers, try to stay within short range but not directly above them.

(22) Be alert for any signs of trouble. Go at once to help any diver who surfaces unexpectedly. Before letting him submerge again, make absolutely sure he is not in distress.

Ascent

(23) At the end of time at diving depth, signal the buddy or the tender and start for the surface. Breathe continuously and naturally during the entire ascent. *Do not hold breath.*

(24) Do not exceed the rate of ascent specified in the decompression table applicable to the dive. If decompression is necessary, follow the applicable table, using proper techniques (3.2.5).

Leaving the Water

(25) When he surfaces, the diver may be very tired. Help him in every way possible. If he can board more easily without some equipment, remove his weight belt and scuba while he is still in the water. Give him a hand to get aboard, taking care not to let him fall.

(26) As soon as the diver is on board, have him dry himself. If the air is cold, give him warm, dry clothing or blankets.

Postdive Inspection

(27) The diving supervisor is responsible for the postdive inspection.

(*a*) As the diver leaves the water, check him for any signs of sickness or injury resulting from the dive.

(*b*) Check his equipment thoroughly to see if it has been damaged.

(*c*) Ask the diver to make a report of any defects that he noticed during the dive.

(*d*) Have corrective and preventive maintenance undertaken as soon as possible after the dive.

3.2.5 DECOMPRESSION

(1) Decompression may become necessary in any dive when the breathing medium contains a high percentage of inert gas. The diving supervisor normally plans the dives to avoid decompression entirely. When decompression is unavoidable, he must provide adequate handling for it.

(2) In general the arrangements and techniques for decompression are the same for any type of scuba although the decompression table may differ from the Standard Air Decompression Table. If the decompression requires a shift from one gas to another (as it does for helium-oxygen diving), the technique becomes more complex. The diving supervisor then has an even greater responsibility than usual to make adequate provisions for decompression (sec. 1.5).

(3) The bulk of self-contained diving involves open-circuit scuba charged with air. The following discussion applies primarily to air decompression for open-circuit scuba dives on air. For dives with other types of scuba or other breathing media, modify the procedures as necessary to make them compatible with the proper decompression table.

Arrangements

(4) Routine procedures for a scuba dive simplify handling decompression when the need arises. If possible, make the following provisions a routine for any self-contained diving operation:

(*a*) Give the timekeeper primary control of the ascent. Require divers to obey ascent and decompression signals without question.

(*b*) Provide communication with the diver. Any simple set of depth and time signals is satisfactory. A slate on a line is adequate.

(*c*) Require divers to check routinely before passing 20 feet to learn what decompression they must take there. If they need deeper stops, be sure to signal well in advance.

(5) When the need for decompression becomes certain, the diving supervisor must make adequate provisions to handle the situation.

(*a*) Provide decompression depth markers. A weighted line with knots every 10 feet is adequate. Weight the line heavily enough to keep it completely vertical in a strong current. In large swells or high waves, place the surface marker 5 feet below the surface. On a rolling vessel, set it 10 feet under the surface. Require the diver to hold the line just below the proper marker in any comfortable position when the lower part of his body is not above the marker.

(*b*) Provide an auxiliary air, mixed-gas, or oxygen supply at the first decompression stop; any adequate self-contained or surface-supplied apparatus is satisfactory. Do not force the diver to surface for an additional gas supply in the middle of his decompression.

Techniques

(6) There are four techniques for decompression in self-contained diving:

(*a*) The surface-supply technique uses a hose that can supply gas for a mask or demand regulator. The diver shifts to the surface supply at the first decompression stop and uses it for the entire decompression.

(*b*) A second scuba is a standby apparatus lowered to the first stop which can also supply gas for the decompression.

(*c*) For surface decompression an adequate pressure chamber can provide surface decompression which may replace some or all of the required water decompression.

(*d*) The original scuba, if decompression requirements are slight, may provide all of the decompression. If no other technique is available, the original apparatus must provide as much of the decompression as possible.

Decompression Tables

(7) The situation may require the diver to use any combination of the techniques listed. Regardless of which technique the diver uses, apply the following rules in determining what decompression to give him.

(*a*) Use the Standard Air Decompression Table when breathing air throughout the dive (original scuba, second scuba, surface-supply, or recompression chamber without oxygen).

(*b*) Use the Oxygen Surface Decompression Table when oxygen is available in the recompression chamber.

(8) For an air dive, use the proper decompression table in part 1.

(9) For nitrogen-oxygen dive, find the proper equivalent air depth and use that depth to make an entry in the proper decompression table in part 1.

(*a*) Use the Standard Air Decompression Table when breathing a gas mixture (or air) throughout the decompression.

(*b*) Use the Oxygen Surface Decompression Table when oxygen is available in the recompression chamber.

(10) For other gas mixtures, use the appropriate decompression table in part 1.

Interrupted Decompression

(11) The diver may have to surface before getting his full decompression. This situation is much more probable in self-contained diving than it is in surface-supplied diving. The diver may complete his decompression by returning to the water or by entering a recompression chamber. In either case, use the applicable procedure for interrupted decompression as given in part 1.

Surface Decompression

(12) Surface decompression is a valuable procedure in self-contained diving. It reduces the exposure to low water temperatures, and it eliminates the air-supply problem associated with water decompression. When a chamber is available at the scene of operations, use surface decompression as a routine measure where feasible. Follow the procedures indicated in part 1.

SECTION 3.3 EQUIPMENT

3.3.1 CLASSIFICATION OF APPARATUS

(1) Scuba is classified by the characteristics of its breathing circuit. The classification indicates: (a) the amount of rebreathing which occurs in the system, and (b) the relationship between the amount of gas supplied to the system and the amount exhausted from the system.

(2) There are two general classes of scuba:

(*a*) *Demand-type or open-circuit scuba.*—In demand systems, the diver inhales directly from the gas supply. He exhales each breath to the surrounding water without reinhaling it. Nearly all the gas supplied to the system is exhausted from the system.

(*b*) *Closed-circuit scuba.*—In a closed-circuit system, the diver inhales from a breathing bag. He exhales each breath back to the breathing bag through a purifying canister. Very little of the gas supplied to the system is exhausted from the system.

(3) Demand-type scuba is further subclassified:

(*a*) In the completely open circuit, no intentional rebreathing occurs. Most apparatus use a completely open circuit.

(4) Closed-circuit scuba is further subclassified:

(*a*) In the completely closed circuit, none of the gas supplied to the system is deliberately exhausted to the water.

(*b*) In the semiclosed circuit, some of the gas supplied to the system is deliberately exhausted to the water. The exhaust is either continuous or intermittent with each breath.

(5) The use of underwater breathing units in the Navy is increasing constantly. At the present time, three classes of scuba are in service: demand-type, closed-circuit, and semiclosed-circuit scuba. The demand-type scuba is the most common. It is a general-purpose "workhorse" in a wide variety of applications. Closed- and semi-closed-circuit scuba are limited in number. They are specialized equipment for particular military applications.

3.3.2 SCUBA COMPONENTS

(1) Full descriptions of each of the three classes of scuba appear in sections 3.4, 3.5, and 3.6. However, certain components are common to all three classes. This article describes such common components. Descriptions of components peculiar to a specific type of scuba appear in the article for that type.

(2) Throughout this article, the term "closed-circuit scuba" includes the term "semi-closed-circuit scuba" unless the latter appears separately.

Cylinders

(3) The scuba gas supply consists of one or more high-pressure cylinders. They are usually aluminum alloy, but may be steel or other special material. Open-circuit scuba cylinders are frequently called tanks. Closed-circuit scuba cylinders are frequently called flasks or bottles.

(4) The pressure rating of a cylinder should be clearly stamped on the cylinder. If made of steel, the stamp generally includes the Interstate Commerce Commission (ICC) classification and the test dates. When charging the steel cylinders, never exceed 10 percent over the pressure rating. Aluminum cylinders do not have an ICC classification; they should *never* be deliberately charged beyond the stamped working pressure.

(5) The space inside a cylinder is its internal volume. It is expressed as follows:

(*a*) The volume of open-circuit scuba is expressed in cubic feet and/or cubic inches.

(*b*) The volume of closed-circuit scuba is expressed in liters, cubic inches, and/or cubic feet.

(6) The capacity of a cylinder is the amount of gas (measured at surface conditions) which the cylinder holds when charged to the pressure

rating. Capacity is expressed in cubic feet or in liters (1 cubic foot is 28.32 liters, and 1 liter is 0.0353 cubic foot).

Stop Valves

(7) A stop valve is a valve that controls the release of high-pressure gas from the cylinder. It may either be in the neck of a cylinder, or on a manifold connecting two or more cylinders.

Manifold

(8) A manifold is a high-pressure connecter joining two or more cylinders and providing a high-pressure outlet to the breathing system. If each cylinder has a stop valve, the manifold can supply gas from any cylinder or from any combination. If the individual cylinders have no stop valves, the manifold must have a stop valve at the high-pressure outlet, and the manifold can supply gas only from all cylinders simultaneously.

Gas-Supply Controls

(9) Beyond the high-pressure outlet there is always some device to reduce the high cylinder pressure to low breathing pressure. Frequently there is a pressure regulator to reduce cylinder pressure to a low, intermediate pressure for the gas-supply control. If not, the gas-supply control works directly from high pressure. Common control devices are—

(*a*) Control valves.
(*b*) Demand regulators.
(*c*) Metering orifices.
(*d*) Bypass valves.

Breathing Bag

(10) The breathing bag is a component of closed-circuit scuba. It is a flexible bag containing the breathing medium at surrounding water pressure. It is located near the lungs. The usual location is either (a) on the back, (b) around the neck, or (c) on the chest. If the breathing bag is located too far from the lungs, it subjects the lungs to high hydrostatic pressure differentials which make breathing difficult.

(11) Breathing bags may be made from various flexible materials. The most common materials are (a) sheet rubber, (b) rubberized fabric, and (c) treated nylon. Breathing-bag shapes vary through a wide range. Rectangular, oval, horseshoe, and doughnut-shaped bags may be used depending on the basic design.

Breathing Tubes

(12) Breathing tubes are flexible, large-bore breathing ducts. They are usually corrugated rubber tubes, or they may be rubberized fabric with metallic ring or spiral stiffening.

(13) Breathing tubes are an important part of most scuba. They provide breathing passageways for inhalation from the apparatus and for exhalation to the apparatus, allowing the head to turn freely without kinking the tubes. Breathing tubes should have a relaxed length equal to the direct distance they span and should extend freely at least twice this distance without collapsing the corrugations. For adequate lung ventilation and minimum breathing resistance, the inside diameter of a breathing tube should be no less than 1 inch.

(14) Breathing systems usually have at least two breathing tubes: the inhalation tube and the exhalation tube. In standard breathing circuitry, the inhalation tube is on the diver's right side and the exhalation tube is on his left side.

Mouthpiece Assembly

(15) A mouthpiece is a special tube which provides breathing gas to the diver's mouth. It is molded of rubber, neoprene, or plastic. It usually has a flange and two bits. The flange fits between the lips and the teeth. The bits are on either side of the mouthpiece opening. They serve to space the teeth restfully apart.

(16) A slight pressure with the lips is usually sufficient to maintain a seal around the flange. Do not clamp hard on the bits or chew on them. They are primarily spacers, not grips. In an emergency the bits give a reliable grip on the mouthpiece only if they are not weakened from chewing. Under special circumstances (such as coughing), it may be necessary to use a hand to hold the mouthpiece in place.

(17) The mouthpiece assembly includes all breathing circuit components between the mouth and the breathing tubes. It may include a mouthpiece connecter, cutoff valves, breathing check valves, and a surface breather valve. Most commonly it consists of the mouthpiece and a simple T-connecter for the breathing tubes. The

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cleaning procedure for this assembly is as follows:

(*a*) Disassemble breathing hoses and mouthpiece.

(*b*) Clean all exposed parts by scrubbing with detergent (DETERGENT, SURGICAL, 5 ounces) and suitable brushes (for hoses, BRUSH, FLASK, 4½ inches; for mouthpiece, BRUSH, TEST TUBE, 1⅛ inches). The interior surfaces of air hoses must be thoroughly scrubbed.

(*c*) After rinsing with fresh water, immerse all rubber parts in a 100-ppm chlorine solution for at least 2 minutes prior to reassembling. One-quarter ounce of CALCIUM HYPOCHLORITE, TECHNICAL (70 percent available chlorine) in 12 gallons of water approximates a 100-ppm chlorine solution. Mouthpiece assemblies containing metal parts should be sterilized in a noncorrosive disinfectant (DISINFECTANT, GERMICIDAL AND FUNGICIDAL, 1 quart; or DISINFECTANT, GERMICIDAL AND FUNGICIDAL, 1 gallon). Disinfectant must be completely removed from the apparatus before it is used.

Special Valves

(18) There are several special valves used in scuba. They are—

(*a*) Breathing check valves.
(*b*) Exhaust valves.
(*c*) Relief valves.
(*d*) Drain valves.
(*e*) Cutoff valves.
(*f*) Surface-breather valves.

Breathing Check Valves

(19) Breathing check valves direct the flow of inhalation and exhalation through a breathing system. They are classified by the flow which they permit. An inhalation check valve allows gas to pass during inhalation, and closes tightly during exhalation. An exhalation check valve allows gas to pass during exhalation, and closes tightly during inhalation. The valves should lift and seat with the smallest possible pressure differential, and should be large enough to allow high rates of gas flow without excessive breathing resistance.

(20) The primary consideration in the use of breathing check valves is the minimization of dead space in the breathing system. Examine breathing check valves regularly, preferably after every operation, to look for foreign matter or corrosion. Anything that holds the valve off its seat will permit rebreathing and may add excessive dead space to the system.

Exhaust Valves

(21) The exhaust valve is an impotrant component in open-circuit and semi-closed-circuit systems. It is a special check valve which discharges excess gas from the system, without letting water enter. Descriptions of the various types of exhaust valves appear in the sections covering open-circuit and semi-closed-circuit scuba.

Relief Valves

(22) A relief valve is a special spring-loaded exhaust valve. It opens when the pressure in the breathing system reaches the desired safety limit. Its primary function is to prevent rupture of the breathing bag or tubes during accidental overpressurization. An exhaust valve may serve the same purpose, and some scuba rely on the exhaust valve for pressure relief. However, if the exhaust valve can be secured shut (as in some semi-closed-circuit scuba), the system should also have a relief valve.

(23) The relief valve will not accommodate a large flow of gas. Exercise care when opening the manual control valve of high-pressure cylinders.

Drain Valves

(24) Some scuba may have a special drain valve to discharge water from some part of the breathing system. The drain valve may be part of a water trap, or may simply be the lowest point in the breathing system. The valve is usually a relief valve with a heavy spring loading and a manual override.

Cutoff Valves

(25) Many scuba, particularly closed-circuit systems, have cutoff valves. These valves isolate the breathing system from the face mask or mouthpiece. This permits the diver to breathe surface air without contaminating a closed system, or to drop a mouthpiece without flooding the system.

(26) A cutoff valve may be a poppet, a shell-and-tube assembly, a stopcock, or any other quick-acting valve with large gas passages.

Surface-Breather Valves

(27) Some scuba provide for breathing air at the surface without removing the apparatus. This feature is useful for gas conservation during standby periods, and for purging closed-circuit scuba prior to breathing from the bag. A surface-breather valve is usually a quick-acting cutoff valve which opens to the outside rather than to the breathing system. It may be a part of a snorkel arrangement, but does not usually serve as the snorkel itself.

Canisters

(28) The absorption canister is a component of closed-circuit scuba. It is a container for the chemical absorbent that removes carbon dioxide from exhalation and may take a variety of shapes. Most often it is cylindrical or flat. The design must provide for adequate filling so that the absorbent does not settle in use leaving a bypass channel along the canister wall. Figure 3–26 illustrates common defects and primary causes of canister failure, assuming that fresh absorbent is used.

(29) Most canisters are made of molded fiber glass or metal. Canisters are rugged enough to withstand normal handling. They usually have watertight filling caps for easy filling or changing of the absorbent. They may have baffles or be spring loaded to insure against channeling and to increase the path of gases through the absorbent without increasing breathing resistance excessively. There are screens at the inlet and outlet of a canister to hold the absorbent in place. These screens may be spring-loaded caps and used to keep the absorbent compacted. Loose absorbent tends to channel the gases, shake excessively, and form dust.

(30) Generally, the exhalation tube discharges to the canister and the inhalation tube draws directly from the bag. It is undesirable to have the inhalation tube draw from the canister because chemical activity in the absorbent

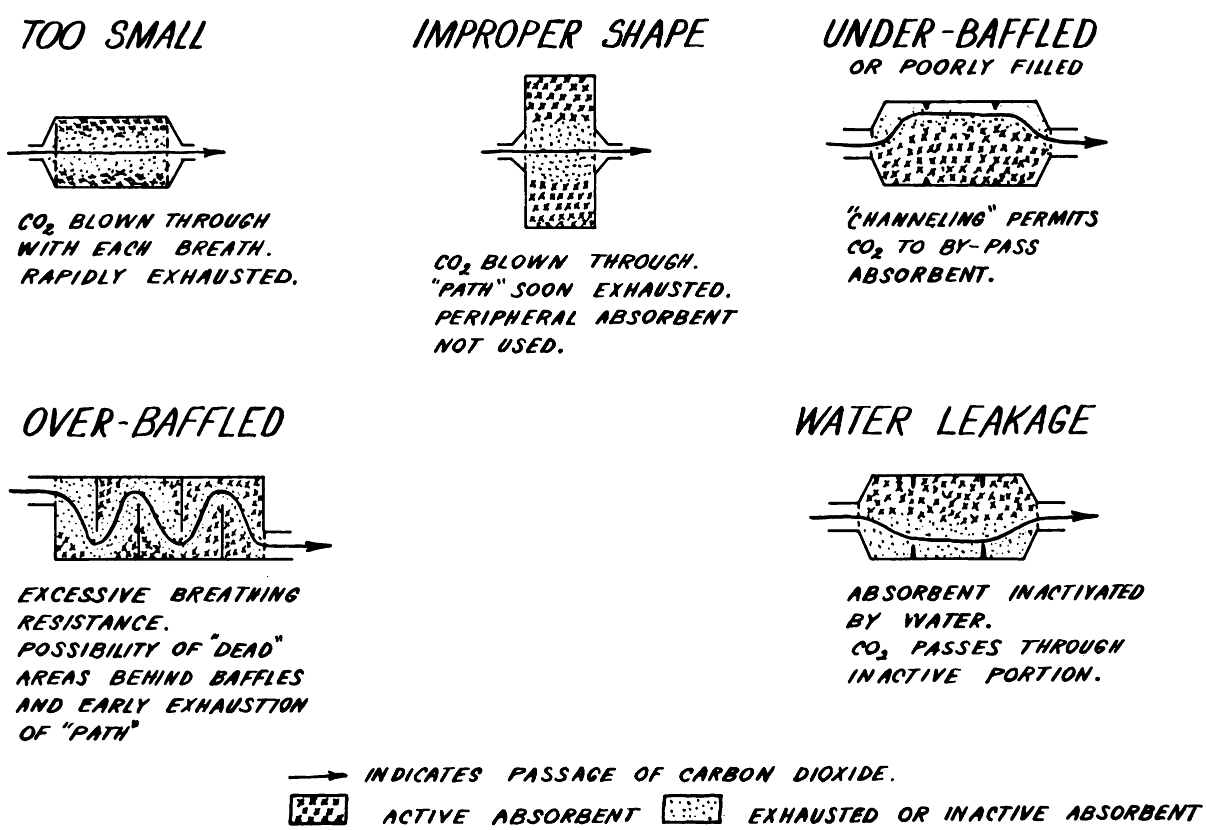

FIGURE 3–26.—Common defects in absorption systems.

makes the gas uncomfortably hot for breathing and increases the probability of inhaling dust.

(31) The canister configuration generally minimizes breathing resistance and maximizes absorbent utilization. The canister should provide at least 2 hours of absorbent capacity for 0.8-knot swimming. Experience indicates that a canister volume of 1,600 cc on a recirculating system will provide adequate capacity. This canister volume will sustain a diver during 4 to 6 hours of rest.

(32) Wet absorbent loses its ability to absorb carbon dioxide. Canister design must insure that there is absolutely no leakage. Breathing-system design should insure that saliva and condensation do not reach the canister.

(33) The canister may be in any convenient location, but it must not contribute excessive drag to swimming characteristics of the apparatus.

Absorbents

(34) There are various chemicals that can remove carbon dioxide from exhaled gas. Most of them are highly caustic. The suitability of an absorbent for scuba is limited by its causticity, susceptibility to dusting, and reaction to moisture. Hyperoxides (widely used in rescue breathing apparatus) cannot be used in scuba because they may react violently upon contact with water.

(35) At present the absorbent used in scuba is Baralyme. This absorbent has the disadvantages of bulk and relative inefficiency. Soda lime has a higher efficiency but is more caustic. Baralyme is relatively insoluble, and its granular form is convenient to handle. Some absorbents, including Baralyme, contain an indicator which changes color on exhaustion. Do not rely entirely upon the color change because its accuracy is limited.

(36) All absorbents require careful handling and adequate facilities for storage. Provide a way to remove dust when filling canisters. Exercise care not to be overenergetic in screening and filling. Excessive shaking of the canister simply forms more dust. Effects of inhaling Baralyme dust are not serious, but they can be very annoying to the diver.

(37) Fill canisters for closed-circuit scuba with absorbent immediately prior to use. Renew the absorbent after each dive or any time it becomes wet. Never use bulk absorbent that has been exposed to air for a long period of time. Always use fresh absorbent.

Face Mask

(38) The face mask is a mandatory component of any scuba. A face mask protects the diver's eyes and nose from the surrounding water so that he may breathe with ease. In clear water with adequate illumination, it also enables the diver to see. This facility is minor in comparison to the psychological value of protecting the diver's eyes and nose from water.

(39) There are two general classes of face masks: the separate face mask and the full face mask. The separate face mask (or swim mask) is normally used for diving with a mouthpiece scuba, for diving without breathing equipment (skindiving), and for surface swimming.

(40) The face mask consists of a faceplate, a faceblank, and a head harness or head strap. The faceplate is a transparent plate. For maximum visibility and protection, it should be made of a flat safety glass having at least 80 percent transmissibility. The faceblank is a flexible, shaped carrier that holds the faceplate off the face and provides a watertight seal. It is rubber compound with soft sealing edges. It may have a rigid frame to hold the faceplate. It may have a nose pocket or a chin pocket, or both. The head harness is a set of adjustable straps that holds the faceblank against the head. For a separate face mask, the head harness usually consists of a single strap.

(41) The full face mask with a half-mask built in for breathing is essential when it is necessary to talk underwater. Intelligible conversation with a mouthpiece is difficult because proper articulation is impossible, although some scuba divers become very adapt at reconstructing speech fractured by a mouthpiece.

(42) The full face mask usually encloses the face under the chin, along the cheekbones, and across the temples.

(43) A separate face mask is employed with scuba having a mouthpiece for breathing. It is also used for surface swimming and for skindiving. It usually encloses the face under the nose, along the cheeks, and across the temples,

leaving the mouth exposed for breathing through a mouthpiece.

(44) Ventilation across the faceplate is generally poor in any face mask, and the glass tends to fog easily. To minimize fogging, thoroughly smear the inside of the faceplate with saliva and rinse lightly prior to donning. If the faceplate fogs during use, admit a small amount of water into the face mask and roll it across the fogged areas.

(45) In some special face masks the head harness may be a hood covering the entire head including the ears. When descending with such a face mask (or any other covering over the ears), be sure to admit gas under the hood to the outer ears to prevent external ear squeeze.

(46) Full face masks may have special fittings for various purposes. The most common are: (a) breathing-tube connecters, (b) cutoff valves, (c) drain valves, and (d) surface breathers. Separate face masks rarely have special fittings.

3.3.3 SCUBA ACCESSORIES

Minimum Equipment

(1) Except for the breathing apparatus and the face mask, all the equipment listed for the scuba diver (3.2.4) is accessory gear. Swim trunks are an esthetic requirement rather than a vital matter, but the other accessories are absolutely necessary for the diver's safety.

Lifejackets

(2) There are two lifejackets approved for use with scuba. The UDT lifejacket is used for surface swimming and shallow diving missions. When fitted with an 18-gram CO_2 cartridge, it is capable of lifting 19 pounds of dead weight from 18 feet. The Mk III yoke-type life preserver is used primarily with semi-closed- or closed-circuit apparatus. It is fitted with four 31-gram CO_2 cartridges. When inflated at depth, it will lift 19 pounds of dead weight from 200 feet. Care should be used to insure use of proper cartridges. If 18-gram cartridges are used, it will lift only 12 pounds from 200 feet. If it is necessary to use these preservers to assist in ascent, be sure to breathe or exhale continuously all the way to the surface. Life preservers should be inspected periodically as required by chapter 9330, article 9330.50, of NAVSHIPS Technical Manual. This inspection should include weighing of the CO_2 cartridges to insure that they have not been punctured or have not lost any of their charge. Cartridges weighing 3 grams or more below the gross weight marked on the cartridge should be discarded and replaced with full cartridges.

Belt and Knife

(3) The scuba diver must carry a knife sheathed in a scabbard on a suitable belt. The knife is the diver's safeguard against entanglement. Secure the knife to the belt with a lanyard to prevent loss.

(4) Three types of knives are in common usage: (a) the standard diver's knife, (b) the standard combat sheath knife, and (c) for scuba divers engaged in areas suspected of magnetic mines, a nonmagnetic knife (Mk I, Mod 0) is provided. The nonmagnetic knife is similar in design to the standard diver's knife as described below. Because of the limited quantities available and the high cost of production, the nonmagnetic knife should not be used on routine missions.

(*a*) *Description.*—The nonmagnetic knife is a hollow-ground, cobalt-alloy blade attached to a reinforced handle. The blade is 7 inches long and 1 inch wide with a round point: one side is a keen edge; the other is serrated. The overall length of the knife is 12 inches. A hole at the top of the handle permits the attachment of a lanyard. The knife is carried in a reinforced plastic scabbard. The bottom of the scabbard is open with a reinforced hole near the bottom to permit the attachment of a lanyard. The knife is held in the scabbard by an internal clip and two nylon keeper straps around the handle. The scabbard may be attached to a standard pistol belt by a sewn loop of heavy-duty nylon. The pistol belt is force fitted to the loop in the following manner. Twist the female belt fastener so that the fastener lies flat lengthwise on the belt; then, force the fastener through the loop by pulling it with pliers. The knife and scabbard may be worn in a horizontal position by unfastening the top keeper strap and tying the scabbard to the belt with a piece of line passed through the reinforced hole in the scabbard.

(*b*) *Use.*—The nonmagnetic knife is primarily for use by activities having explosive ordnance disposal capability. The knife is a *SPECIAL-PURPOSE KNIFE* for use only on missions requiring low magnetic effect (signature) equipment; it *DOES NOT REPLACE THE COMBAT KNIFE* as the general utility knife. The serrated edge is not intended for use as a general-purpose saw, but is to facilitate the cutting of water-soaked fiber lines or the puncture of lightweight fabric bags or metal containers such as flotation bladders or common tin cans. The knife should not be abused—hacking, chopping, and prying should be avoided when practicable. Abrasives or sand should not be used to clean the knife, because these substances will destroy the nonreflecting coating (see (*f*) below).

(*c*) *Identification.*—Each knife is identified by permanently stamped markings on the underside of the handguard, as follows: U.S.; NONMAGNETIC (standard symbol for equipment or material with low magnetic effect).

(*d*) *Magnetic effect* (*signature*).—The magnetic effect of the assembled knife and scabbard, at a distance of 4½ inches from the assembly, is ¹⁄₁₀ of a millioersted, or less. Contamination of the knife by foreign matter, such as salt incrustations from dried sea water, or the collection of debris in the scabbard, may cause an increase in the magnetic effect. For this reason, the knife (and scabbard) should be cleaned by washing and flushing it with fresh water after each mission.

(*e*) *Corrosion resistance.*—The knife (and scabbard) will not corrode when exposed to ordinary sea water or sea atmosphere. Preservative oils or greases are not required for storage.

(*f*) *Sharpening.*—*POWER GRINDERS MUST NOT BE USED TO SHARPEN* the nonmagnetic knife. Power grinders disturb the molecular structure of the cobalt alloy, causing the blade to become brittle and easy to break. The blade is finished to a Rockwell C hardness of 53 to 57, the same hardness used for ordinary steel knives. The keen edge of the blade can be maintained by occasional sharpening with a small (3 in. x ⅞ in. x ⅜ in.), fine grit, silicon carbide hand hone. The blade is purposely finished with an oxide, nonreflecting coating; when sharpening, care must be taken to preserve the coating.

Swimfins

(5) Flexible fins for the feet are an important accessory. Without swimfins, the scuba diver cannot propel himself adequately. They are particularly valuable for swimming to the surface in an emergency ascent. Even when diving with negative buoyancy, the scuba diver should use swimfins.

(6) Swimfins increase the propulsive force transmitted from the legs to the water. For maximum efficiency they should have a large blade and considerable rigidity. However, if the blade is too large or if the fin is too rigid, there is excessive back pressure on the fin which quickly produces fatigue. On the other hand, if the blade is too small or if the fin is too flexible, there is insufficient thrust which also produces fatigue.

(7) Comfort is an important factor in the use of swimfins. Tight or loose fins can chafe and blister the feet, putting the diver out of action for several days. Wear an efficient, comfortable pair of swimfins. Be sure they fit well. Use a larger size over a suit or protective covering for the feet.

Other Accessories

(8) A number of additional accessories are highly desirable for a scuba dive. Of these, the depth gage and wristwatch are most important.

Depth Gages

(9) The Mk I Mod 0 depth gage is a nonmagnetic depth gage with a 0- to 200-foot range. Each division on the dial represents 10 feet of sea water. Alternate divisions are marked, i.e., $2 \times 10 = 20$ feet. A second gage, the Mk II Mod 0, is to be procured for issue after operational evaluation. It is also nonmagnetic but has a 0- to 50-foot range. Each division on the dial represents 2 feet of sea water. Numerals are used to mark each 10 feet (see app. D and fig. 3–27).

Wristwatch

(10) A pressureproof wristwatch (fig. 3–27) is essential to the scuba diver for computing time of dive, controlling rate of descent and ascent, and for timing various operations. A pressureproof, nonmagnetic wristwatch that in-

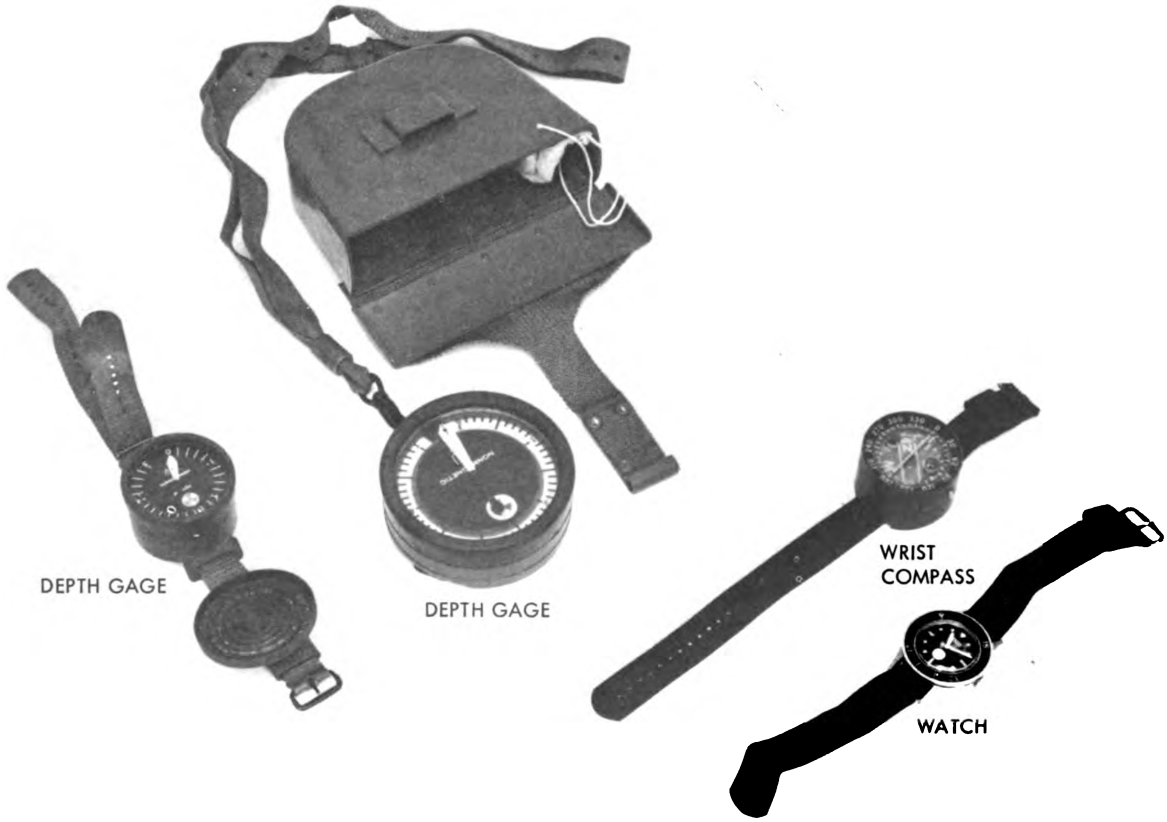

FIGURE 3-27.—Depth gages, wrist compass, and watch.

corporates certain desirable features is available from the Ships Parts Control Center, Mechanicsburg, Pa. For efficiency, the watch must be used and maintained in accordance with instructions issued by the Naval Ship Systems Command. Repairs to the nonmagnetic watch will be accomplished only at Norfolk Naval Shipyard.

Wrist Compass

(11) Scuba divers commonly use a magnetic wrist compass for underwater navigation. In spite of its inherent inaccuracies, this compass is valuable in any underwater operation, and is especially valuable if visibility is poor. A pressureproof wrist compass (fig. 3-27) is available from the Ships Parts Control Center, Mechanicsburg, Pa.

Signal Flare

(12) The Mk 13 Mod 0 Signal (Distress, Day and Night) is a valuable piece of safety equipment. It is especially helpful at night when the diver wants to be picked up or is in trouble. It may also be used for other purposes, such as indicating the beginning or end of an operation.

(13) Secure the signal flare to the knife belt. The night-signal end of the flare has a circle of raised beads around the outside. When using the signal flare, hold it at arm's length and point it away from the body about 45° above the horizontal.

Slate

(14) A sheet of plastic with both surfaces sanded can serve as a writing slate for carrying instructions and for recording information when underwater visibility is good. Attach a pencil to the slate and either secure the slate to the knife belt, or to a lanyard around the neck.

(15) In murky or dark water the slate is practically useless. Efforts to develop luminous slates have not been successful.

Lifelines

(16) The buddy line is *6 to 10 feet long.* At night or in poor visibility, each of the buddies secures one end of the line to himself.

(17) The float line is long enough to reach from the desired depth to the surface. The diver secures one end around his body (not to his equipment). The tender secures the other end to a float.

(18) The surface line is long enough to reach from the desired point of operation into the tending vessel. The diver secures one end around his body (not to his equipment).

Floats

(19) The float is usually an inflated bladder that is secured to the upper end of a float line. However, it may be any other suitably shaped and colored buoyant object.

Protective Clothing

(20) Part 2 describes protective clothing completely. Cool water usually requires only diver's woolen or thermal underwear. Cold water requires at least a wet exposure suit. Very cold water requires a dry exposure suit and diver's woolen or thermal underwear.

(21) When the diver has to operate around coral, in shallow water, or on the beach, he should wear lightweight shoes (coral shoes are available) under his swimfins to protect his feet.

Noseclip

(22) Some divers find a noseclip helpful for equalizing pressure in the ears and sinuses. A properly adjusted noseclip is comfortable and does not interfere with pressurizing the separate face mask, or with expelling water. It can be valuable for keeping the nose dry upon flooding or losing of a face mask. However, every diver should be able to remove and replace his face mask under water without a noseclip, and many divers do not use a noseclip at all.

Earplugs and Goggles

(23) *Never use earplugs.* They prevent pressure equalization of the outer ear and can cause external-ear squeeze. In some cases the plugs may drive through the eardrum and destroy the auditory bones in the middle ear. If the diver cannot expose his outer ears to pressure or to water, he should not dive.

(24) *Never use goggles.* They prevent equalization of the eye sockets and cause eye squeeze.

3.3.4 MAINTENANCE AND HANDLING

Approved Equipment

(1) Do not use breathing equipment in operations unless it has received official evaluation and approval. Trials of experimental gear and new products of reputable manufacturers are permissible, but only with adequate safeguards.

Maintenance

(2) Maintain equipment in optimum condition at all times. Set up routines of periodic inspection and preventive maintenance. Adhere to them rigidly. Keep records on all complete units and major components. Correct all defects, however minor, before using equipment.

(3) Cover all components of breathing apparatus in the inspection and maintenance routine. Include harness and other adjuncts as well as the breathing circuit itself.

(4) Give particular attention to reducing valves, demand regulators, and air-reserve devices. Field maintenance of these components is not always practical.

(5) Be sure that face masks, suits, flotation gear, knives, compasses, and other accessories also receive proper maintenance and handling.

(6) Inspect cylinders for any sign of impending failure. Have them tested hydrostatically at intervals depending on the type and on the conditions of use, in accordance with appendix D, section 5, of part D–C.

(7) Inspect all high-pressure connections frequently and give them hydrostatic tests periodically. Be sure to include charging connections that may be a particular hazard.

(8) Calibrate gages periodically to insure accuracy (see app. B).

(9) Give diligent maintenance to compressors and associated equipment necessary for charging scuba. Operate them carefully. Their output must be free of dust, excess moisture, excess oil vapor, and toxic gases. Have air samples analyzed periodically.

(10) Provide checkoff lists for predive inspection and tests of breathing apparatus by individual divers. Include tests for gas and

water leaks, for operation and position of control, for determination of cylinder pressure, and for any special procedures necessary for specific apparatus.

(11) Report immediately any defects noted during the operation of an apparatus. Make certain they are corrected before the apparatus is used again.

(12) The principle of making each man responsible for his own equipment is very sound. However, where special skills are required for maintenance and repair, as is the case with some valves and other intricate mechanisms, utilize trained maintenance personnel in the field or establish a central repair shop.

(13) Provide an adequate supply of spare parts in order to forestall hazardous makeshifts. Only spare parts procured from SPCC shall be used in the maintenance of scuba unless otherwise directed.

Handling

(14) Give proper attention to handling and stowage of apparatus. Breathing apparatus is particularly easy to damage. Handle it carefully during use or diving transportation, and stow it properly in a dry place away from excessive heat.

(15) Prevent corrosion of metal parts and rapid deterioration of rubber parts by washing parts with fresh water and drying thoroughly after use.

(16) Handle cylinders carefully to prevent any kind of damage. Treat aluminum and alloy cylinders with particular respect. Remember that a charged cylinder with its valve broken off becomes a rocket.

(17) Charge cylinders carefully. Charge them slowly to prevent overheating. *Never* charge steel cylinders more than 10 percent above the rated (stamped) pressure. *Never* charge aluminum cylinders above their stamped working pressure.

(18) Use charging connections cautiously to avoid kinking or rupture. A flexible charging connection with high-pressure gas escaping from the end can be a deadly whip.

(19) Keep charged cylinders away from excessive heat. Store cylinders with valves closed and with some pressure remaining inside. Before charging or attaching a cylinder to an apparatus, crack its valve slightly to blow out any dirt that may have entered the open end. Do not leave charged cylinders in direct sunlight.

(20) Use open-end wrenches of proper size. Do not use adjustable wrenches. Never force a fitting.

(21) Exercise extreme care to prevent oil or organic materials from coming into contact with oxygen under high pressure (or with high-pressure streams of escaping oxygen) because of the danger of explosion or fire. Such contact may occur in numerous ways:

(*a*) Cylinders, valves, gages, and fittings not specifically intended for use with oxygen frequently contain oil.

(*b*) Oily residues may be left in components which have been previously used with compressed air. Attempts to clean such equipment using volatile solvents are hazardous.

(*c*) Maintenance operations may leave oil from tools or fingers on valves and reducers if precautions are not taken.

(*d*) Handling of connections or use of oily or dirty wrenches may deposit oil or expose oil to escaping oxygen.

(*e*) Uninstructed personnel may unintentionally lubricate valves and fittings with volatile materials, producing disastrous results.

(*f*) Mixing oxygen and compressed air or other gases under pressure is hazardous unless the air or gas is water pumped and oil free.

(22) The precautions regarding oil also apply to grease, graphite-base lubricants, pipe dope not intended for oxygen fittings, and most paints and enamels. There is no objection to normal lubrication of apparatus exposed to oxygen under near-atmospheric pressure, but volatile materials must not be used.

SECTION 3.4 OPEN-CIRCUIT SCUBA

3.4.1 GENERAL

(1) Open-circuit scuba derives its name from the fact that the breathing medium is used only once. In the open-circuit system, rebreathing does not occur; the expired gases are discharged into the water during exhalation. Normally compressed air is the breathing medium used in open-circuit scuba; however, it is possible to use mixed gases for deep dives.

(2) Open-circuit systems are inherently wasteful of gases. About three-fourths of the oxygen in each breath drawn from the cylinder is discharged into the water during exhalation of air. Consequently, a diver needs a much greater volume of gas than he would require with a rebreathing system.

(3) There are two basic systems in open-circuit scuba: the continuous-flow system and the demand system. The demand system is the only one currently used by the Navy. There are various adaptations of the demand system and its components which will be explained in detail in this section.

(4) Depth is the primary factor in determining the operating limits of open-circuit scuba. Depth reduces the air-supply duration and produces nitrogen narcosis, the possibility of oxygen toxicity, and decompression problems. Normal limits of a dive should be within the depths and times requiring no decompression.

3.4.2 BASIC SYSTEMS

Continuous-Flow System

(1) This system is merely a self-contained substitute for the ordinary air hose with continuous flow. Because the flow not only has to meet the demands of inspiration, but continues to flow during expiration, the cylinder must provide at least twice the diver's minute volume of respiration. The waste will soon exhaust a portable cylinder. A reservoir bag arranged to accumulate incoming air during the expiratory phase can permit the use of lower flows and can reduce waste. In either arrangement, the flow has to be adjusted to meet changes in the diver's respiration. Such systems have been used in scuba, but they are usually impractical.

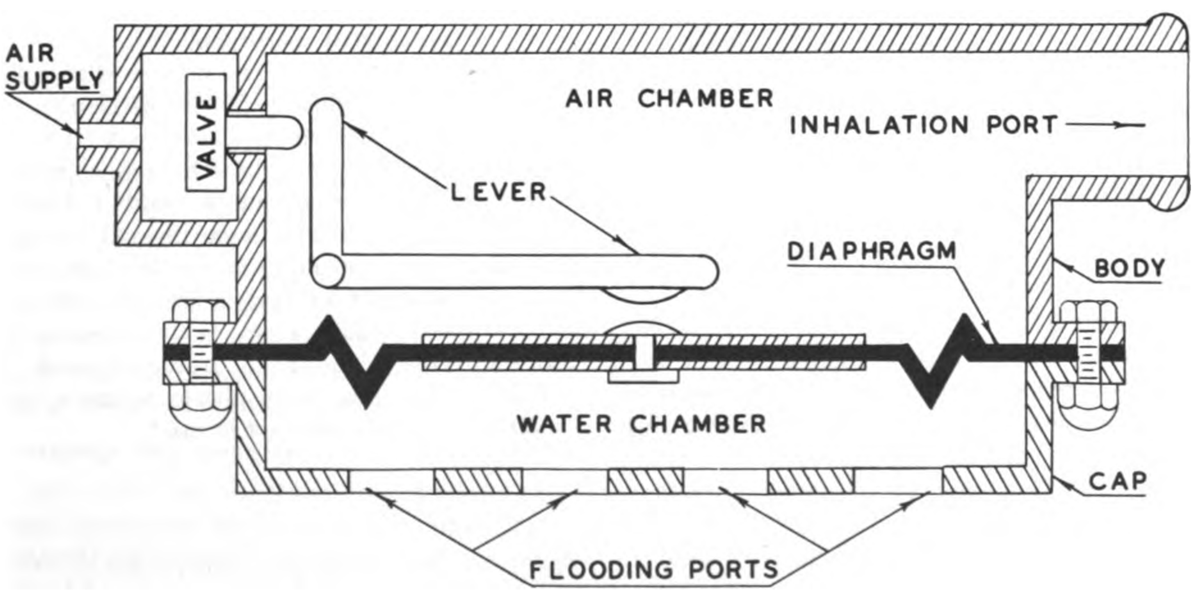

FIGURE 3-28.—Basic demand regulator.

Demand System

(2) Release of the compressed gas to meet only inspiratory requirements permits considerable conservation of the gas supply. A demand regulator controls the release automatically. This is a special low-pressure regulator that maintains the breathing system at ambient depth pressure, opening to slight negative pressure at the beginning of inspiration and remaining open until the end of inspiration.

(3) Successful adaptation of a demand regulator to diving apparatus is not as simple as it might seem. It is a relatively recent development. It was almost revolutionary because it made use of compressed air in self-contained apparatus really practical for the first time. The demand system is virtually the only type of open-circuit apparatus now in use. Figure 3-28 is a schematic diagram of a basic demand regulator.

(4) The schematic diagram in figure 3-29 shows the open-circuit demand system.

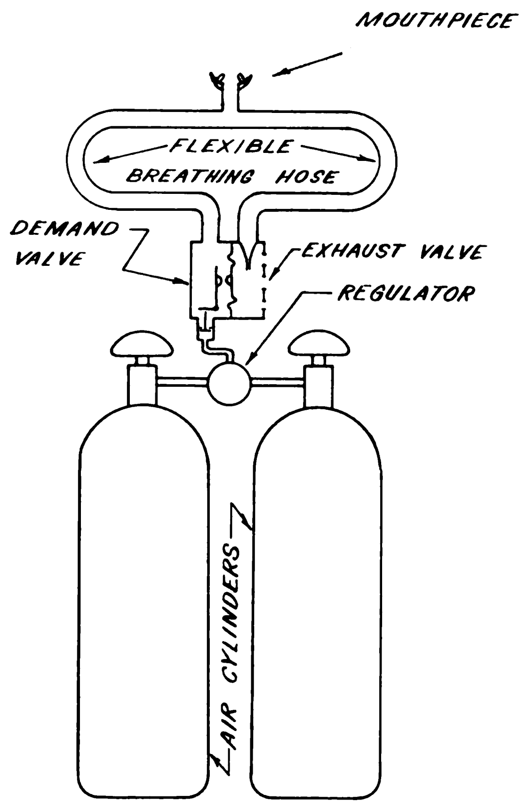

FIGURE 3-29.—Open-circuit system with cylinder-mounted regulator.

3.4.3 COMPONENTS

(1) Open-circuit scuba systems are generally made up of the following basic components: (a) cylinders, (b) air-reserve mechanism, (c) check valves, (d) demand regulator, (e) breathing tubes, (f) mask or mouthpiece, or both, and (g) exhaust valve.

Cylinders

(2) The cylinders, sometimes referred to as bottles or flasks, contain the breathing medium, and are constructed of either galvanized steel or aluminum. They are specially constructed to withstand the high internal pressure of the compressed breathing medium, usually 2,150-psi pressure for galvanized cylinders and 3,000-psi pressure for aluminum cylinders, and must meet Navy Department specifications. Steel cylinders must be marked in accordance with ICC regulations. The date of the last hydrostatic test and the pressure rating are stamped on all cylinders issued by the Naval Ship Systems Command. Prior to charging the individual cylinder, it is mandatory to check these data to insure safe charging.

(3) Volumes of the individual cylinders vary with the different arrangements in use. The cylinders are usually worn on the diver's back and fastened to the divers by an arrangement of waist, shoulder, and crotch straps. A means for quick release of these straps for emergency ditching of the cylinders must be provided.

(4) Compressed-gas cylinders are designed to be safe for the purpose for which they were intended. Serious accidents connected with their handling, use, and stowage can almost invariably be traced to abuse or misuse. General safety rules governing the use of compressed-gas cylinders can be found in NAVSHIPS Technical Manual 9230. They are based upon accident-prevention experience and must be observed in the handling of compressed gases. Do not assume, however, that these rules cover every necessary safety procedure. Make due allowances for the hazards that may be peculiar or incidental to local conditions of handling, stowage, and use.

Air-Reserve Mechanisms

(5) All open-circuit scuba must have an air-reserve mechanism to provide a positive warning to the diver that his gas supply is becoming

critically low. The most common mechanism is an air-reserve valve which permits free flow of gas to the regulator until the cylinder pressure falls to a predetermined level (approximately 300 to 500 psi, depending upon the type of scuba used). At this pressure the valve restricts the air, causing increased breathing resistance. With this signal, the diver opens the air-reserve mechanism, thereby allowing free flow of the reserve air supply. This reserve air supply is sufficient to allow the diver to return safely to the surface, provided that he does not prolong the dive and that he does not need decompression. The means of opening the air-reserve mechanism varies with the different types of scuba.

Demand Regulator

(6) The demand regulator is a device that controls the flow of the breathing medium from the cylinders to the diver. All regulators presently used by the Navy have demand valve mechanisms allowing release of the breathing medium at a pressure equal to that of the surrounding water and at a rate required by the diver.

(7) Figure 3–28 illustrates the basic principles of the demand regulator. When inhalation reduces the pressure in the air chamber below the pressure in the surrounding water, the diaphragm deflects toward the air chamber, depressing the lever, and opening the valve on the air supply. As long as inhalation continues, the valve remains open and admits air to the system. When inhalation ceases, rising pressure in the air chamber returns the diaphragm to its original position and the air supply valve closes.

(8) Demand regulators consist of two stages. The two-stage regulator is merely a single-stage unit mounted upon another single-stage unit called the first-stage regulator. The first-stage regulator provides an intermediate reduction in the gas pressure through a high-pressure valve to approximately 100 psi more than the depth pressure. The second-stage regulator then provides the final reduction through a low-pressure valve prior to the release of the breathing medium to the diver. There are several acceptable demand regulators of both types in present use.

(9) Demand regulators are usually mounted on the cylinder, but may be mounted in the face mask. Cylinder-mounted demand regulators conveniently minimize the need for medium-pressure tubing, but because of the hydrostatic differential in pressure between the demand regulator and the effortless breathing point of the diver, they make inhalation slightly difficult until the body adjusts to these factors. Mask-mounted demand regulators minimize the hydrostatic differential making breathing comparatively easier and eliminating the necessity for a mouthpiece.

Breathing Tubes

(10) Breathing tubes currently used on open-circuit scuba consist of nonkinking, corrugated, or bellows-type rubber or neoprene hoses. There is usually an inhalation tube and an exhalation tube. The inhalation tube carries air from the demand regulator to the mouthpiece, and the exhalation tube carries the expired gas to the exhaust valve where it is discharged into the water.

Check Valves

(11) An open-circuit scuba may use three types of check valves: inhalation, exhalation, and exhaust. Breathing check valves may be incorporated into the mouthpiece, and a check valve is always a component of the exhaust-valve assembly.

(12) The inhalation check valve prevents exhaled air from entering the inhalation tube. Equally important, it prevents water from entering the demand regulator when the mouthpiece floods.

(13) The exhalation check valve prevents water in the exhalation tube from flooding the mouthpiece, and prevents rebreathing of expired air. Both valves must be present to minimize dead space. The valves greatly simplify the problem of clearing water from the breathing system.

(14) The exhaust check valve prevents water from entering the system. All open-circuit scuba have at least one check valve, the exhaust valve.

Mask and Mouthpiece

(15) Open-circuit scuba may use a full face mask, a mouthpiece, or a combination of the two to supply gas directly to the diver. Full

face masks usually have the demand regulator mounted directly on the mask. Mouthpiece and mouthpiece-mask combinations are commonly used with breathing tubes and cylinder-mounted demand regulators.

Exhaust Valves

(16) An exhaust valve is used with all open-circuit scuba to allow exhaled gas to leave the system. It may be of the rubber disk (mushroom) or flutter type as shown in figure 3–30.

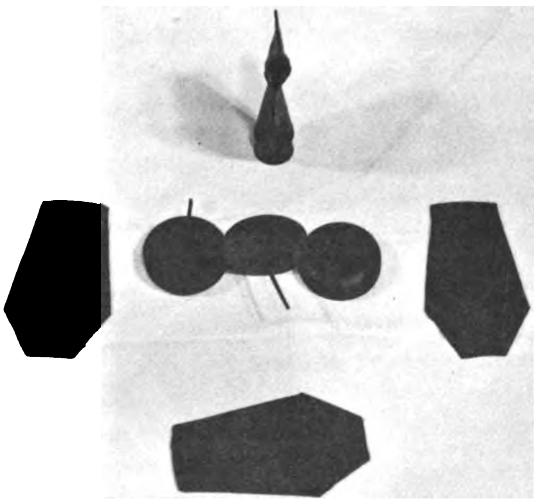

FIGURE 3–30.—Mushroom and flutter valves.

The valve is held in the closed position by hydrostatic pressure. During exhalation, the breathing-system pressure becomes slightly higher than the hydrostatic pressure and opens the exhaust valve, allowing the exhaled gas to escape into the water. When the diver begins inhaling, the pressure on the exhaust valve drops below the hydrostatic pressure and the valve closes. This action prevents water from entering the system through the exhaust side of the circuit. To prevent excessive loss of gas, there must be some way to keep the hydrostatic pressure on the exhaust valve at or near the level of the pressure on the demand regulator. This may be accomplished either by locating the exhaust valve close to the demand regulator or by utilizing a pressure balance hose from the demand regulator to an exhaust pressure regulator.

3.4.4 APPARATUS

(1) Figure 3–31 shows a demand-type apparatus used in the Navy. The first-stage regulator, demand valve regulator, and exhaust valve form an integral unit mounted on the high-pressure manifold attached to the cylinders. The cylinders are worn on the back. They are fastened to the diver by a harness assembly. They are worn with the manifold up so that the demand regulator rides the back of the neck. A corrugated breathing tube supplies gas from the demand regulator to a mouthpiece. Another corrugated tube carries the exhaled gas from the mouthpiece to the exhaust valve which discharges the gas to the water. The position of the exhaust valve close to the demand-regulator diaphragm minimizes the hydrostatic differential between the two so that inhalation and exhalation occur at nearly identical hydrostatic pressures. The air-reserve mechanism is integral with the manifold and is located above one of the cylinders. It is manually operated by means of a pull rod.

(2) A more detailed description of the demand-type apparatus used in the Navy appears in appendix D. Check the applicable publication prior to using the apparatus (app. D).

3.4.5 BREATHING MEDIA

Air and Other Gases

(1) Theoretically, any respirable gas or gas mixture can be the breathing medium in open-circuit demand systems. In practice, for all but very unusual circumstances, only compressed air is satisfactory. It may sometimes be easier to obtain oxygen, but oxygen is very dangerous for two reasons.

(*a*) Previous charging with air may have left a residue of oil vapor which can cause an explosion when charging with oxygen.

(*b*) Oxygen tolerance imposes very shallow depth limits. These limits are not normally associated with open-circuit equipment, and it is too easy to forget them.

(2) DO NOT USE OXYGEN IN OPEN-CIRCUIT SCUBA.

(3) Nitrogen-oxygen mixtures are advantageous only beyond 60 feet. Helium-oxygen mixtures are advantageous only beyond 200 feet, and require a complicated decompression procedure not readily adaptable to open-circuit

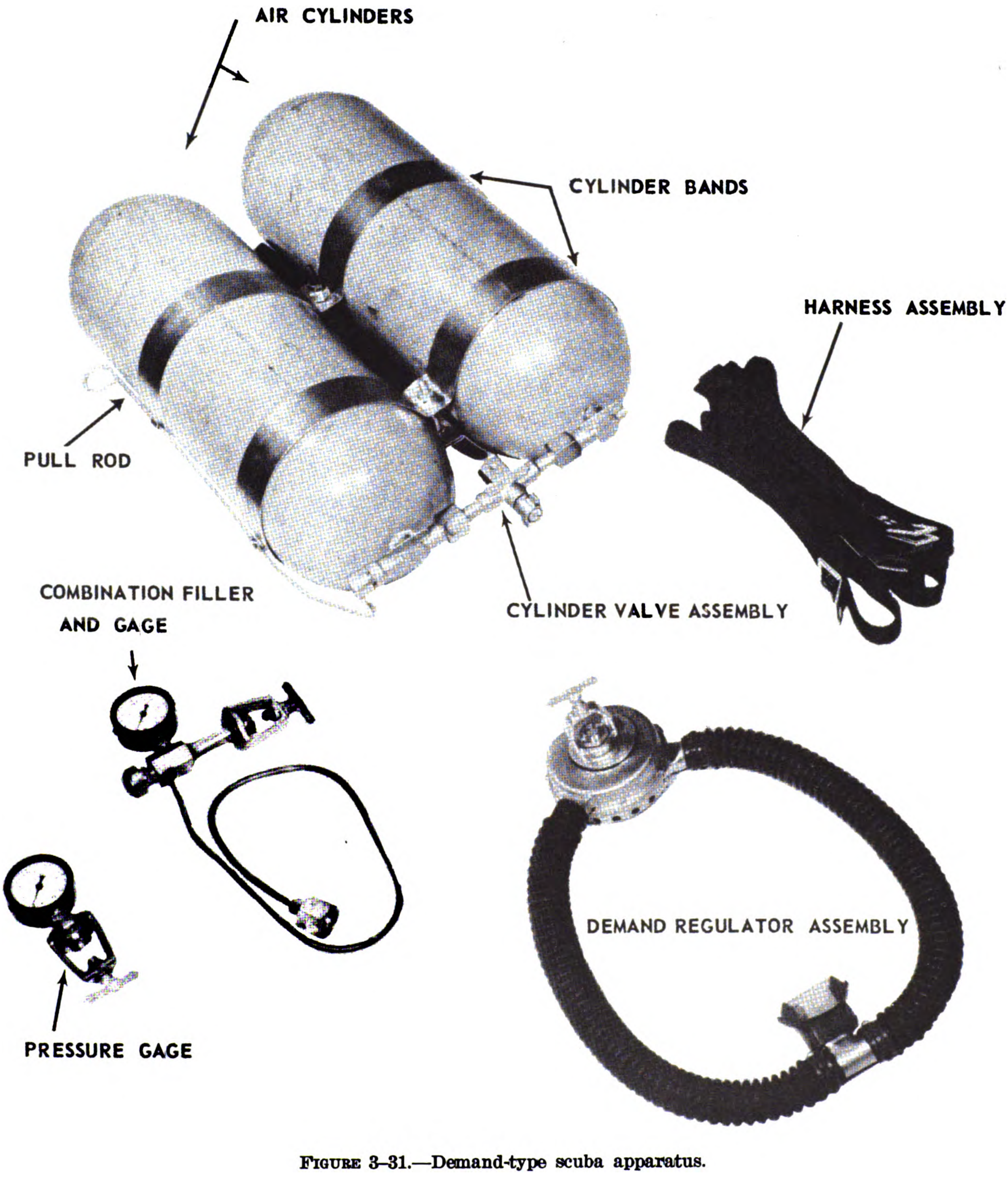

FIGURE 3-31.—Demand-type scuba apparatus.

scuba. At depths of 60 feet or more, however, the reduction of gas-supply duration in open-circuit scuba cuts off the advantages of special gas mixtures. Use of mixed gas is not practical in open-circuit scuba.

Purity

(4) To be a satisfactory breathing medium, compressed air must be free from carbon monoxide, carbon dioxide, oil vapor, and other impurities. Examine oil and dust filters in the charging system frequently to insure their cleanliness. Check the locations of the air intake in the charging system often to insure that air intake is not near engine or machinery exhaust.

(5) Analyze compressed air periodically for impurities. (See the limits given in app. B for compressed air.)

Sources

(6) The following naval facilities are generally satisfactory sources for obtaining high-pressure air:

(*a*) Torpedo shops.
(*b*) Naval air stations.
(*c*) Submarines.
(*d*) Submarine-rescue vessels.
(*e*) Submarine tenders.
(*f*) Destroyer tenders.
(*g*) Aircraft carriers.
(*h*) Explosive-ordnance demolition teams.
(*i*) Underwater demolition teams.

(7) When utilizing any particular source for the first time, test the air for impurities, especially carbon monoxide. These sources do not usually have connections for scuba. It may become necessary to construct a special yoke and high-pressure fitting to charge scuba.

(8) When naval facilities are not available for charging scuba, civilian agencies which supply compressed oxygen can usually supply compressed air. In many cities a satisfactory source of high-pressure air is the charging station for the compressed-air breathing apparatus used by fire departments. Many sports-equipment agencies have facilities available for the charging of diving equipment used for skin-diving. In addition to the above sources, there are on the civilian market several inexpensive, lightweight, portable air compressors which are specifically designed for the charging of scuba and which have proven quite successful.

3.4.6 PHYSIOLOGICAL CONSIDERATIONS

(1) Open-circuit equipment has some physiological advantages over other types of breathing apparatus. So long as the breathing medium lasts and the demand regulator functions properly, there is no possibility of oxygen deficiency. If dead space is minimal, there is no probability of carbon dioxide excess. If the breathing medium is air, there is little danger of oxygen poisoning except at extreme depths. Except for these advantages, all physiological considerations applicable to self-contained diving in general (art. 3.1.4) also apply to open-circuit apparatus. This is particularly true for the problem of decompression.

3.4.7 DURATION

Depth Effect

(1) Depth is the primary factor determining the duration of open-circuit scuba. At depth each breath requires a greater mass of gas than the same breath requires at the surface. The total time available for a given gas supply at a constant volumetric breathing rate diminishes inversely with the absolute pressure. For example, at 100 feet (4 atmospheres) a gas supply gives only one-fourth of the time that the same supply gives at the surface.

(2) For various surface durations, figure 3–32 shows the theoretical reduction in duration as depth increases. These curves assume a constant rate and volume of breathing at any depth.

Exertion Effect

(3) Physical exertion also affects gas-supply duration. Because the work rate can vary greatly from dive to dive, the duration of the given gas supply can also vary greatly, even at the same depth. For rough calculations, an average requirement by a man performing moderately hard work is 1 cubic foot of air per minute at the measured depth.

Individual Experience

(4) For more accurate timing, keep a check on your own consumption for each dive. Become familiar with the air-supply duration in a particular apparatus under specific work and depth conditions. When you have a good idea of

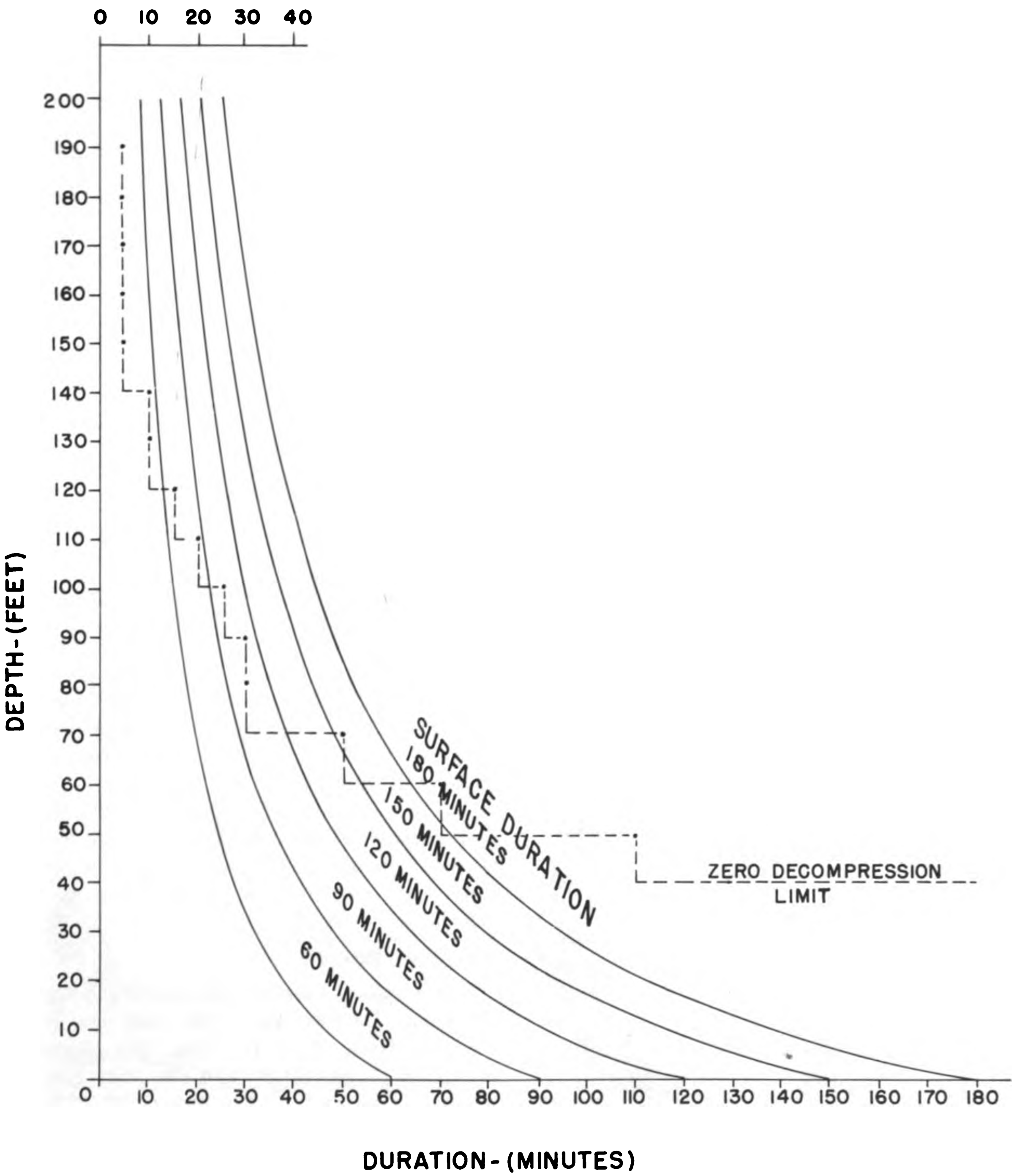

FIGURE 3-32.—Theoretical air-supply duration.

the duration at a particular depth, set that point on figure 3–32 and draw a light line parallel to those shown. This line will indicate the probable duration at other depths for the same apparatus and work conditions. It will also show the relationship between the probable duration and the no-decompression curve for air.

3.4.8 USE

(1) Prior to using any scuba, be thoroughly familiar with all applicable safety precautions and emergency procedures. Also be indoctrinated in the particular apparatus you are to use. Complete all preliminary preparations and inspections under the supervision of the diving officer or his representative. Remember that the greatest single safety factor in scuba diving is the use of the buddy system.

Preliminary Preparations

(2) In addition to the general preliminary preparations, carry out the following procedure:

(*a*) Gage all cylinders *immediately* before entering the water to insure that there is sufficient breathing gas for the dive.

(*b*) Immediately after gaging, attach the regulator to the gas supply. Open the cylinder stop valves to determine if there are any leaks in the air-supply system.

(*c*) Take several slow breaths on the mouthpiece or in the mask to ascertain that the regulator is functioning properly.

(*d*) Check breathing tubes by moderately pulling on them to insure that they are tightly secured to the regulator and mouthpiece or mask.

(*e*) *Close the air reserve mechanism.*

(*f*) *Personally check* the lifejacket and its gas cartridge to insure readiness for operation. Prior to use, the jacket should be orally inflated and checked for air leaks. Periodically, the jacket should be submerged in water to check for leaks.

(*g*) Don the accessory diving gear.

(*h*) When all equipment tests out satisfactorily, don the scuba. Secure the harness with slip hitches to insure quick release in an emergency.

(*i*) Open the cylinder stop valves.

(*j*) Report to the diving supervisor who should closely observe and supervise the above preparations.

Predive Inspection

(3) Before the diver enters the water, the diving supervisor must conduct the following predive inspection:

(*a*) Check for all items listed above under "Preliminary Preparations."

(*b*) Check that the diver knows clearly the purpose of the dive.

(*c*) Check the diver's buddy.

(*d*) Put both men in the water at the same time.

(4) If the diver is to have surface tenders instead of a buddy, the tenders will assist the diving supervisor to insure that the predive inspection is complete.

Surface Check

(5) On entering the water, the divers will stop at the surface and make the following checks on equipment:

(*a*) Utilizing the weight belt, adjust buoyancy to be slightly negative on full inhalation. (Positive buoyancy increases throughout the dive because of the continuous loss of gas from exhalation.)

(*b*) Check the scuba for satisfactory operation and the buddy's scuba for leaks of any sort.

(*c*) Check the face mask for proper seal to minimize flooding.

(*d*) Report any inadequacies or malfunctions of equipment to the diving supervisor. Correct any deficiencies before making the descent.

The Dive

(6) Upon completion of the surface check, the buddies signal each other that they are ready to dive. When both are sure of each other's readiness for the dive, and only then, they signal the diving supervisor (and timekeeper) and commence the dive. Follow the general procedures for the dive and ascent (sec. 3.2.4).

Decompression

(7) When possible, plan scuba dives to eliminate the need for decompression. However, if decompression is required, surface personnel must rig the descending line or some other surface line with markers placed at appropriate

depths for the decompression stops. If available, use a diving stage for the decompression.

(8) For open-circuit scuba dives on air, use the Navy Standard Air Decompression Table. Follow the procedures previously outlined (sec. 3.2.5).

Postdive Inspection

(9) As the diver leaves the water, check him for any signs of sickness or injury resulting from the dive.

(10) Inspect the equipment thoroughly to determine if it has received any damage. Report any defects noted during or after the dive. Undertake corrective and preventive maintenance as soon as possible after the dive.

(11) Before removing a cylinder-mounted demand regulator, close the cylinder stop valves. Inhale from the system to discharge air remaining in the manifold. This action breaks the seal and simplifies removal of the regulator from the manifold.

3.4.9 MAINTENANCE

(1) Open-circuit scuba is rugged, but it can be damaged if it is not given reasonable care. Keep the cylinders, regulators, hoses, tubes, and mask assemblies clean, especially after use in sea water. There should be little necessity for corrective maintenance. Ultimately, with the best of preventive maintenance, corrective maintenance becomes necessary. Prior to disassembling, repairing, adjusting, and reassembling scuba components, refer to the applicable NAVSHIPS instruction books for detailed instructions on the particular apparatus.

(2) Observe the following preventive maintenance procedures for open-circuit scuba:

(*a*) Always stow a cylinder-mounted regulator separately from the cylinders. Never leave the regulator attached in stowage.

(*b*) After use in sea water, thoroughly rinse the regulator and associated assemblies in fresh water. Hang the regulator to dry by its yoke.

(*c*) Do not allow any water to enter the high-pressure air inlet of a regulator. Insert a rubber stopper into the yoke immediately after detaching a cylinder-mounted regulator. Keep it in place when rinsing. Remove it only before mounting the regulator.

(*d*) When washing the regulator, pour fresh water into the mouthpiece several times. Make sure that both the inhalation and exhalation sections of the regulator and breathing tubes are well rinsed.

(*e*) Make a regular inspection of rubber exhaust valves to see that salt deposits do not lodge around the edge and cause leakage.

(*f*) Rinse the air cylinders and high-pressure manifold thoroughly in fresh water to remove all traces of salt deposits. Stow the cylinder assemblies carefully when not in use.

(*g*) Compressed air stored for long periods does not show signs of contamination; however, it is advisable to change the air every year.

(3) Establish a definite maintenance schedule to insure that all scuba are kept in top operating condition.

(*a*) Provide for the disassembly and overhaul of regulators, tubes, hoses, and masks every 6 months as described in the applicable NAVSHIPS instruction books.

(*b*) Also provide for a continuous check on the hydrostatic test date for cylinders to insure that they are kept up to date in accordance with NAVSHIPS instructions. Every 3 years, each aluminum compressed-gas cylinder must be submitted for inspection and tested in accordance with the procedures described in the NAVSHIPS Technical Manual.

(4) Stow cylinders fully charged and gage the pressure weekly. If pressure falls below 1,500 psi, recharge the cylinders to insure availability for emergency dives.

SECTION 3.5 CLOSED-CIRCUIT SCUBA

3.5.1 GENERAL

(1) Closed-circuit scuba derives its name from the fact that rebreathing occurs continuously, and that there is no loss of gas to the surrounding water unless there is an excess created within the system. Rebreathing necessitates provision for three special needs: (a) purging of the system, (b) supply of the breathing gas, and (c) removal of carbon dioxide generated by the diver.

(2) The breathing gas used in closed-circuit scuba is oxygen. *Never* use air or mixed gas.

(3) There are certain limitations in the use of closed-circuit scuba, such as depth, rate of work, exposure time, efficiency of the absorption system, and so forth.

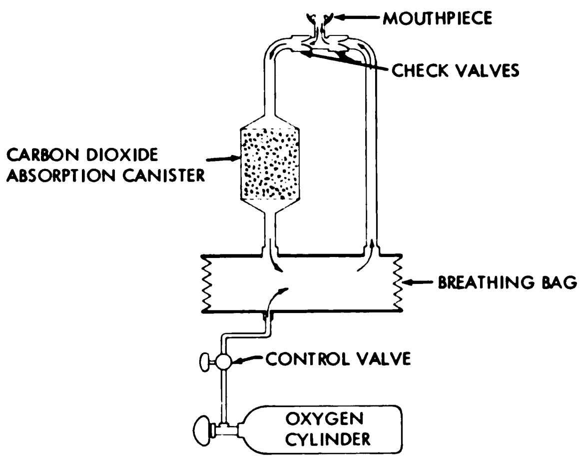

FIGURE 3–33. Closed-circuit oxygen recirculating system.

3.5.2 BASIC SYSTEMS

(1) Basic systems of closed-circuit scuba derive their names from the method of circulating breathing medium through the absorbent.

(2) Components of closed-circuit scuba must include an oxygen supply, an oxygen-control valve, a rebreathing bag, a mask or a mouthpiece, a carbon dioxide absorbent canister, and breathing tubes.

Recirculating System

(3) In the recirculating system, separate tubes provide for inhalation and exhalation. Breathing check valves maintain one-way flow of the breathing medium. Rebreathing does not occur until the exhaled gas has been passed through the carbon dioxide absorbent. Dead space of this design is therefore relatively insignificant. Figure 3–33 illustrates this system which is predominant in American and German designs.

Adaptations

(4) Various navies, diving concerns, and interested divers have developed adaptations or variations of the basic closed-circuit systems, either to meet certain needs or to improve upon earlier designs. In the recirculating systems, variations in the location of one-way check valves in the circuit have occurred as well as variations in the location of the absorbent canister and to the breathing bag. The inhalation tube may lead to a mouthpiece or a full face mask.

(5) Changes and improvements in the design of components have led to further variations to meet new requirements.

3.5.3 COMPONENTS

(1) Divers using closed-circuit scuba must have a thorough knowledge of the technical aspects, functions, and arrangements of the various components. Most of this information appears in section 3.3, "Equipment." The following discussion covers additional points peculiar to closed-circuit scuba.

Cylinders

(2) Closed-circuit scuba cylinders of various manufacture have different capacities and pressure limits. They are made of several types of material. Practically all of them can be charged with enough oxygen for 1 to 4 hours' use at mod-

erate work and can be charged from 1,500 to 2,000 psi (100 to 136 atmospheres) and should never purposely be charged beyond their rated working pressure.

(3) Care in handling, storing, charging, inspecting, and protecting oxygen cylinders cannot be overemphasized. Rigidly observe the following rules:

(*a*) Never leave oxygen cylinders in stowage completely empty or with the valves open.

(*b*) Never use oxygen cylinders for any purpose other than storing oxygen.

(*c*) Never put oxygen in cylinders that have been used for other purposes.

(4) Violent explosions followed by fires have occurred from mishandling of oxygen.

Gas-Supply Control

(5) All closed-circuit scuba have a means of controlling the high-pressure oxygen from the cylinder to the reduced pressure of the breathing bag. The systems range from direct manual control to automatic metering or demand control. Any arrangement except a manually operated valve must have a manual bypass to give rapid admission of additional oxygen whenever necessary. Use care in operating the bypass to prevent the rupture of low-pressure fittings, overinflation of the breathing bag, and overpressurization of the lungs.

Breathing Bag

(6) The breathing bag on a closed-circuit apparatus contains the oxygen for immediate consumption at the pressure equal to the depth at work. When the amount of gas in the bag becomes less than the volume of a breath, there is a definite cutoff in inhalation. This signals the diver to replenish his oxygen.

(7) While swimming, the diver uses the bag volume to control buoyancy. For a replenishment signal in this case, he uses loss of buoyancy rather than cutoff of breathing.

(8) It may be necessary to flush the breathing bag. This is particularly true if the oxygen supply is impure so that inert gas accumulates in the system. This may also happen if the absorbent fails so that carbon dioxide accumulates. Symptoms of oxygen deficiency or carbon dioxide excess are signals to renew the gas in the breathing bag.

Breathing Tubes

(9) The recirculating system uses two breathing tubes: one for inhalation and one for exhalation.

Check Valves

(10) The recirculating system uses at least two check valves: an inhalation check and an exhalation check.

Canister

(11) In a recirculating system some locations are more desirable than others, but the canister may actually be anywhere in the circuit.

Relief Valve

(12) A relief valve is theoretically not necessary in a closed-circuit scuba because the diver consumes all the gas added to the system. Practically, however, every closed-circuit scuba should have one. Its most important purpose is to prevent rupture of the breathing bag in stowage when the bag cutoff valves are closed and the oxygen cylinder stop valve leaks.

(13) The relief valve may function during a dive if the diver adds too much gas to the breathing system. If it is not set high, it can also act during ascent when expanding gas overpressurizes the system.

3.5.4 APPARATUS

(1) The U.S. Navy pure-oxygen scuba unit is a closed-circuit underwater breathing apparatus and is composed of a mouthpiece shutoff-valve assembly, breathing tubes, inhalation and exhalation breathing bags, carbon dioxide absorption canister, an oxygen-supply cylinder, and a manual gas-flow regulating assembly mounted on a nylon supporting vest. Figures 3–34 and 3–35 show the pure-oxygen breathing apparatus in position ready for use. The complete apparatus assembled for use weighs about 35 pounds out of water, and is approximately neutrally buoyant in use under water.

(2) Compressed oxygen is delivered from the high-pressure oxygen cylinder into the breathing system at the inspiratory breathing bag by means of a hand-operated needle valve, and can also be introduced by means of a manual bypass valve.

(3) Inhalation of oxygen from the breathing bag is accomplished via an inspiratory tube,

FIGURE 3-34.—Pure-oxygen recirculating, underwater breathing apparatus (front view).

FIGURE 3-35.—Pure-oxygen recirculating, underwater breathing apparatus (back view).

passing through a check valve and the mouthpiece assembly to the respiratory passages of the diver. Exhaled gas passes through a check valve and expiratory tube, into the exhalation breathing bag, through a canister for absorption of carbon dioxide, and finally into the inhalation breathing bag.

(4) Refer to the proper technical manual for details (app. D).

3.5.5 BREATHING MEDIA

Oxygen

(1) In any closed-circuit scuba, the gas supply must always be oxygen approved for breathing by Navy specification. In addition, deliberate flushing of the scuba unit and the lungs with oxygen prior to entering the water is required to purge most of the nitrogen from the breathing system.

Purity

(2) In a prolonged dive, the nitrogen present as an impurity in the oxygen supply (usually less than 1 percent) and the nitrogen eliminated from the body (about 1 liter) can produce measurable buildup of inert gas in the breathing medium. Too much inert gas creates the hazard of oxygen deficiency. The condition may occur without warning if the volume of nitrogen is great enough to permit a full breath from the breathing bag. Proper initial purge of the entire system is the most important preventive of oxygen deficiency.

Sources

(3) Breathing oxygen is obtained initially from general-stores issue. It comes in 200-cubic-foot gas cylinders charged from 1,800 to 2,100 psi. Transfer oxygen to the closed-circuit scuba cylinder through a transfer line or

through a manifold employing the cascade method. Gage each oxygen cylinder before and after the transfer of gas to determine the amount available in the cylinder. When the scuba cylinder requires a greater pressure than the source provides, use an oxygen booster pump. Take all precautions to prevent contamination and spontaneous combustion during the charging operation. Refer to the technical manual for proper procedure (app. B).

3.5.6 PHYSIOLOGICAL CONSIDERATIONS

(1) All the physiological effects of self-contained diving apply to diving with closed-circuit scuba except bends and nitrogen narcosis. Closed-circuit scuba emphasizes certain hazards, especially oxygen poisoning, oxygen deficiency, and carbon dioxide excess.

(2) Exceeding the established depth-time limits for oxygen diving (part 1) can result in oxygen poisoning. *Do not use closed-circuit scuba beyond these limits!*

(3) Presence of large amounts of inert gas in the breathing system creates the hazard of oxygen deficiency. Be sure to purge the scuba properly before starting the dive. Purge the system at least once during the dive (at the end of the first hour) and just before starting for the surface. Use the proper procedure for purging under water.

(4) A large number of conditions may result in carbon dioxide excess. In order of frequency the most common are—

(*a*) Absorbent channeling from improper filling.

(*b*) Absorbent inactivation from wetting.

(*c*) Absorbent exhaustion from use.

(*d*) Check-valve failure.

(*e*) Inadequate canister size.

3.5.7 DURATION

Gas Utilization

(1) In a closed-circuit system, the diver consumes all the oxygen added to the system. Waste occurs only on ascent when expansion of the gas exceeds the consumption, or at any time that oxygen is used to eject water from the system. The mass of gas needed for a given dive in closed-circuit equipment is approximately 5 percent of the amount needed for the same duration in open-circuit equipment at the surface.

Gas-Supply Duration

(2) Oxygen consumption is the primary determinant of gas-supply duration in closed-circuit scuba. Oxygen consumption depends on the work rate, but a man can easily carry enough oxygen to last longer than his physical endurance at work under water.

Apparatus Duration

(3) With present absorbents and canisters, carbon dioxide absorption capacity is the primary factor limiting apparatus in closed-circuit scuba.

Depth Effect

(4) Oxygen toxicity limits the safe depth of operation for closed-circuit scuba. Extensive operations are hazardous beyond 30 feet. Part 1 gives the depth-time limits that apply to diving with oxygen.

Exertion Effect

(5) High work rates increase lung ventilation, oxygen consumption, and carbon dioxide production. These factors may overload the breathing system.

(6) Increased lung ventilation may result in noticeable breathing resistance if some section of the breathing circuit is particularly restrictive. Very high lung ventilation (either high rate of breathing or increased volume of breath) may push exhalation through the canister faster than the absorbent can purify the gas. If the canister is too small, this breakdown may occur during normal exertion. Even if the canister is adequate, increased carbon dioxide production exhausts the absorbent more rapidly. Increased oxygen consumption decreases the gas-supply duration.

(7) In general, because of reduced duration either of the canister or of the gas supply, high work rates reduce the overall apparatus duration.

3.5.8 USE

(1) Before using a particular closed-circuit scuba, become completely familiar with the construction, function, and maintenance of the apparatus as outlined by the technical manual. In addition, observe all applicable safety pre-

cautions. The use of an appropriate checkoff list is recommended (app. D).

Preliminary Preparations

(2) Charge the apparatus with oxygen.

(*a*) Connect the oxygen-supply cylinders to the oxygen-charging manifold.

(*b*) Attach the scuba-charging connection to the oxygen-charging manifold.

(*c*) Charge the scuba using the cascade method.

(3) Fill the absorbent canister.

(*a*) Free the absorbent from dust by using a sieve.

(*b*) Remove the refilling cap on the canister.

(*c*) Using a funnel, pour absorbent into the canister, tapping the canister gently to insure complete filling.

(*d*) Replace and tighten refilling cap.

(4) Assemble the apparatus according to the method prescribed in the technical manual (app. D).

(5) Check for leaks.

(*a*) Close the bag cutoff valve.

(*b*) Fill the breathing bag from the oxygen cylinder supply.

(*c*) Submerge the apparatus in water, and look for continuous bubbling.

(*d*) Tighten leaking connections without forcing them. If a connection continues to leak, replace its gaskets.

(*e*) For valve leaks, remove the valve, clean it, and use an approved lubricant.

(*f*) For breathing bag leaks, patch if pierced; tighten connection if leak occurs at joints.

Predive Routine

(6) Gage oxygen supply in the scuba cylinders.

(7) Don the scuba. Do not lift by the breathing tubes or pressure hose.

(8) Purge the breathing system.

(*a*) Open the bag cutoff valve.

(*b*) Inhale from the breathing bag and hold that breath.

(*c*) Close the bag cutoff valve and open the surface breather valve.

(*d*) Exhale to the outside.

(*e*) Repeat steps (*a*) through (*d*) until the breathing bag collapses completely; then leave the bag cutoff valve shut.

(*f*) Use the surface breather until ready to dive.

(9) Just before the dive, check to see if the bag is still flat and then shift from surface breathing to apparatus breathing.

(*a*) Open the oxygen supply bag and inflate it about halfway.

(*b*) Put on a nose clip if desired and don the face mask.

(*c*) Exhale fully to the outside, close the surface breather, and open the bag cutoff valve while the lungs are still empty.

(*d*) Breathe normally from the bag.

(10) Test the operation of the breathing check valves.

(*a*) Crimp the inhalation tube and try to inhale.

(*b*) Crimp the exhalation tube and try to exhale.

(*c*) If you can inhale or exhale, the corresponding check valve is faulty. Correct the defect before trying to dive.

(11) Don the accessory equipment.

(12) Report for the predive inspection.

The Dive

(13) Enter the water, make the surface check, orient yourself, and signal the start of the dive.

Descent

(14) Make a proper descent.

(15) Keep the breathing bag at correct volume during descent. Use the control valve or bypass valve unless the apparatus has an automatic device.

At Diving Depth

(16) Follow routine procedures. Remember that oxygen toxicity limits the safe depth of operation for closed-circuit oxygen equipment. Know the characteristics of the closed-circuit scuba used.

(17) Be alert for signs of apparatus failure, exhaustion of oxygen supply, symptoms of oxygen poisoning, or symptoms of carbon dioxide excess. Keep alert for other troubles peculiar to closed-circuit scuba diving and be prepared to execute emergency procedures.

(18) Observe applicable diving and tending techniques.

(19) Purge the breathing bag at least every hour and just before starting the ascent.

(*a*) Inhale from the breathing bag.

(*b*) Crimp the exhalation tube.

(*c*) Exhale around the mouthpiece or into the mask (break the seal across the forehead to discharge gas into the water).

(*d*) Continue discharging gas from the bag into the water until the bag is flat.

(*e*) Release the exhalation tube and fill the bag to proper volume.

Ascent

(20) Make a proper ascent.

(21) Expansion of gas in the breathing bag during ascent will cause some spillage through the relief valve, mouthpiece, or face mask.

(22) No decompression is necessary for an oxygen dive.

Postdive Routine

(23) Report for the postdive inspection.

(24) Remove the scuba.

(*a*) Close the oxygen cylinder stop valve.

(*b*) Close the bag cutoff valve.

(*c*) Remove the face mask.

(*d*) Unfasten the harness and remove the apparatus.

3.5.9 MAINTENANCE

(1) With careful, regular maintenance and handling, closed-circuit oxygen scuba gives very little trouble.

(2) When diving operations are completed, prepare the scuba for stowage.

(*a*) Disconnect the oxygen cylinders.

(*b*) Dump, rinse, and dry the canister.

(*c*) Rinse and dry the mouthpiece, face mask, and breathing tubes.

(*d*) Examine and clean the breathing check valves.

(*e*) Rinse and dry the breathing bag.

(*f*) Examine and clean other components.

(*g*) Correct defects noted during the dive.

(*h*) After all rubber parts are dry, dust them with talc.

(*i*) Stow the scuba with the oxygen cylinder disconnected and the canister empty.

(3) If the scuba is in stowage for a long period of time, carry out periodic maintenance procedures. Consult the technical manual for special requirements (app. D).

SECTION 3.6 SEMI-CLOSED-CIRCUIT SCUBA

3.6.1 GENERAL

(1) Fundamentally, the semi-closed-circuit system is a special closed-circuit system which utilizes a continuous purge to prevent buildup of inert gas in the breathing medium when the gas supply is a gas mixture instead of a pure oxygen mixture.

(2) In a semi-closed-circuit system, partial rebreathing conserves the gas supply. A certain amount of the breathing medium is intentionally discharged from the system. This type of apparatus is generally used only with nitrogen-oxygen or helium-oxygen mixtures on a continuous or intermittent low-flow basis.

(3) Although it is possible to use any supply mixture within proper depth limits, three mixtures (60, 40, and 32½ percent oxygen) are standard for semiclosed apparatus using nitrogen-oxygen mixtures. Two mixtures (40 and 32 percent oxygen) are standard for helium-oxygen mixtures. A mixture may be used for any depth less than its maximum. For instance, a 40-percent-oxygen, 60-percent-nitrogen mixture with 8 liters per minute flow may be used for a 60-foot nonswimming dive. However, using lower oxygen percentages at higher flows serves no particular purpose if the depth of the dive will permit using higher percentages.

CAUTION

Exceeding the maximum depth for a mixture may result in oxygen toxicity.

(4) Two principal factors determine the endurance of the semi-closed-circuit scuba: (a) the carbon dioxide absorption canister capacity, and (b) the gas-supply duration. For any satisfactory apparatus, the design of the absorption system provides adequate capacity to outlast the gas supply under all circumstances. If the design is not adequate, the technical manuals for the equipment spell out the imposed limits. The technical manuals also specify any special limits of depth, time, and work rate. Observe such limits unless otherwise directed.

3.6.2 BASIC SYSTEMS

(1) The semi-closed-circuit breathing apparatus must have a mixed-gas supply and the basic components of a closed-circuit apparatus.

(*a*) Breathing bags.
(*b*) Carbon dioxide absorbent canister.
(*c*) Mouthpiece, mask, or both.
(*d*) Breathing tubes.
(*e*) Check valves for the breathing circuit.
(*f*) Gas supply.
(*g*) An emergency reserve gas supply.

(2) In addition there are two special components:

(*a*) A reliable automatic injection system for the mixed gas.

(*b*) An adjustable exhaust valve for the excess breathing medium.

(3) The injector is the heart of the semiclosed system. It consists of a pressure regulator and a metering orifice, commonly called a "jet." Usually there is also a special filter to protect the jet from clogging. The most common adaptation of the semiclosed circuit uses continuous injection and intermittent exhaust.

(4) Semi-closed-circuit scuba falls into the same category as closed-circuit scuba; i.e., a recirculating system. Figure 3–36 is a schematic diagram of a recirculating system.

(5) The most common semiclosed system has a constant-mass flow injector to supply the breathing system with mixed gas. Since the injection is at a constant rate of mass flow, the volumetric flow diminishes with depth. The design must provide oxygen at a rate greater than the probable maximum oxygen consumption. Excess gas is discharged from the system through the exhaust valve which is adjustable to meet buoyancy and breathing pressure requirements. This system is well adapted to mathematical analysis for design consideration.

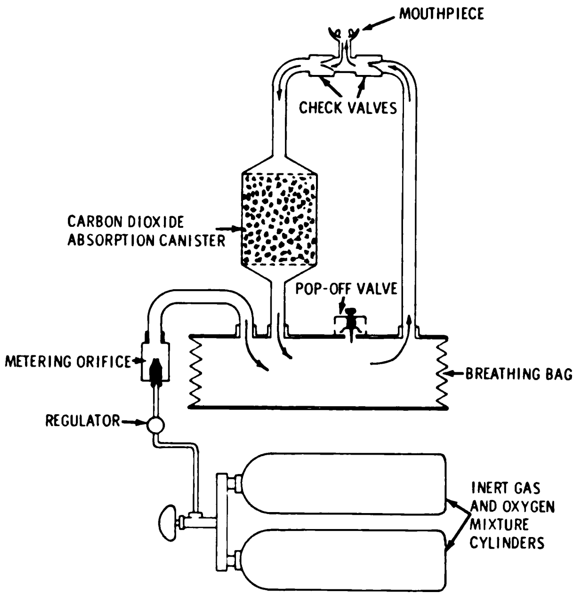

FIGURE 3-36.—Semi-closed-circuit, mixed-gas recirculating system.

3.6.3 COMPONENTS

(1) Semi-closed-circuit scuba are made up generally of the following basic components:

(*a*) Cylinders
(*b*) Manifold
(*c*) Regulator
(*d*) Filter
(*e*) Orifice
(*f*) Bypass
(*g*) Breathing bag
(*h*) Exhaust valve
(*i*) Breathing check valves
(*j*) Breathing tubes
(*k*) Mouthpiece
(*l*) Canister
(*m*) Harness
(*n*) Weights

(2) The paramount consideration in any semi-closed-circuit scuba is reliability. The basic design may include emergency features to provide compensation for apparatus failure. Quick weight release for positive buoyancy is one such feature. A warning device for low gas-supply pressure (or for low-orifice flow) is another. An emergency gas supply either in a separate cylinder or as part of the main supply is a third. In spite of the complexity which they may add, these features are desirable for the diver's safety. Keep these emergency features in operating condition.

Cylinders

(3) In cylinders, the size and pressure rating govern gas capacity. Size often conflicts with compactness, and length and width may govern location and position. For the present concept of mixed-gas diving, an adequate gas supply is two cylinders of 6 liters internal volume each, with at least 3,000-psi pressure rating. An emergency cylinder gives added safety, but it increases overall bulk. Larger main-supply cylinders with appropriate safety devices may be equally satisfactory.

Manifolds

(4) Several considerations determine the advantages of a manifold. Its location is important. If a manifold mounts to either side, it materially affects the swimming characteristics of the scuba diver because the added weight tends to pull the diver down on that side. If it mounts low on his back, it creates a righting coupled with the breathing bag tending to set the diver on his feet and making it difficult for him to swim horizontally. Other important considerations are the number of stop valves. A single stop valve simplifies the design and operation of the apparatus. Individual cylinder stop valves make it easy to replace damaged cylinders.

Regulators

(5) The absolute regulator or metering device is an important component of the gas-metering system. Stability during operation is extremely important in any regulator. Once the flow has been set and the gas cut off prior to the dive, turning the gas on again should not affect the regulator pressure materially.

(6) The regulator connector determines the ease of removing the regulator for maintenance or replacement. The yoke connector is the simplest of regulator connectors, but it limits the size of the manifold valve handle since the yoke has to slip over it. Compact threaded connectors are usually satisfactory. Standard CGA (Compressed Gas Association) connectors are designed for large stowage cylinders. Their relatively large size reduces compactness.

(7) For supersonic orifices, the regulator must be noncompensated to produce constant mass flow. Consequently, the regulator pressure must be at least twice the absolute pressure at the maximum diving depth. If the orifice is not close to the regulator, a length of hose is needed.

This creates a leakage problem. High regulator pressure makes the last part of the main gas supply unavailable.

(8) For sonic orifices the regulator must be especially compensated to produce approximately constant-mass flow. The regulator pressure is usually very low to minimize problems of low-pressure leakage. The low regulator pressure makes almost all the main gas supply available. These features, together with the nonclogging characteristics of the orifice, make the system highly advantageous.

Filter

(9) A filter is vital for a small supersonic orifice. A filter is desirable but less vital for a large sonic orifice. Any filter must be rugged, and the openings must be smaller than the diameter of the orifice. The cross-sectional area which the filter presents to the flow must be large enough to prevent the filter from clogging rapidly. It must also be accessible for maintenance and replacement.

Orifice

(10) The orifice, in combination with the regulator, ideally must provide the same mass flow of gas at any depth between the surface and the limiting depth. If the mass flow changes at all, it must increase, not decrease. A very small supersonic orifice gives excellent stability, but is prone to clog easily. A large sonic orifice requires a special semicompensated regulator to approximate constant mass flow, but it does not clog readily.

Bypass

(11) A bypass is necessary to provide additional gas for volumetric makeup during descent. Where there is no emergency gas supply, a bypass is also necessary to provide an emergency supply if the jet clogs. It must provide at least enough volumetric flow to prevent any squeeze in a rapid fall in the amount of gas, and it must be readily accessible preferably to the left hand.

Breathing Circuit Components

(12) The breathing bag, breathing tubes, mouthpiece, check valves, and canister should have the general characteristics given in section 3.3, "Equipment."

Exhaust Valve

(13) The exhaust valve is an important part of the breathing system. It sets the breathing-pressure level in the system. The main requirements are good modulation, stability, and a wide pressure range. A manual override is highly desirable so that excess gas can be released immediately without disturbing the automatic setting.

3.6.4 APPARATUS

(1) The present semi-closed-circuit equipment is described in detail in appendix D.

3.6.5 BREATHING MEDIA

(1) Part 1 fully discusses the physiological reasons for using gas mixtures in diving. The uses of these gases and the required decompression are also covered in that section. Appendix D further explains the use of these mixtures.

3.6.6 PHYSIOLOGICAL CONSIDERATIONS

(1) Oxygen deficiency is the greatest potential physiological problem in semi-closed-circuit equipment. Poor design, improper use of low-oxygen mixtures, or failure of the injector can cause the oxygen level in the breathing medium to become critically low. At greater depths, the oxygen partial pressure may be high enough that the diver does not react to a very low oxygen percentage until he develops oxygen deficiency during ascent.

(2) Even if oxygen deficiency does not result, the inert-gas percentage may be high enough to produce unexpected bends. (In a properly functioning apparatus bends can occur, but they are very unlikely to occur with proper decompression.)

(3) As long as the diver does not exceed the safe depth for the supply mixture, he is not likely to develop oxygen poisoning. However, accidental use of a high-oxygen mixture can have serious consequences. As in closed-circuit equipment, carbon dioxide excess can occur for a number of reasons. Other physiological considerations which apply to self-contained diving also apply to semi-closed-circuit equipment (1.5.3).

3.6.7 DURATION

General

(1) In general, good design provides satisfactory carbon dioxide absorption capacity so that the apparatus duration is the same as the gas-supply duration. In semi-closed-circuit scuba, the duration of the gas supply is governed by the depth which determines the proper gas mixture and flow setting.

(2) At the present time only semi-closed-circuit scuba is available for self-contained diving with gas mixture. Both nitrogen-oxygen and helium-oxygen are used.

(3) Exertion affects the duration of the apparatus because it requires various flow rates to maintain the minimum bag oxygen level. A greater work rate than is anticipated by predive apparatus flow setting brings the bag oxygen level below that which would prevail with a lesser work rate.

Gas Utilization

(4) During an extended dive, the average oxygen consumption will seldom exceed 2 liters a minute. A representative injection rate for mixed gas is 6 liters a minute. On this basis the maximum gas utilization will be 33 percent. With a constant mass flow injector, the gas utilization is independent of the depth. Consequently, the semi-closed-circuit scuba conserves the gas supply far better than the open-circuit scuba where the utilization is about 5 percent at best and increases greatly with depth.

Gas-Supply Duration

(5) In a semiclosed apparatus with constant mass injection, the gas-supply duration is reliably predictable. An allowance of 10 percent of the supply for volumetric requirements on descent and of another 10 percent for a safety factor covers most contingencies. With constant mass injection of 6 liters a minute at the surface, a 750-liter supply would thus provide at least 90 minutes of diving time regardless of depth. The factors taken into account when determining duration are—

(*a*) Total cylinder capacity (liters).

(*b*) Pressure to which bottles are charged (psi).

(*c*) Safety pressure limit to be left in bottles (psi).

(*d*) Surface rate (liters per minute).

(6) The following formula relates these factors to the gas-supply duration:

$$t=\frac{(V)(p-s)}{(14.7)(f)}$$

where

t = gas-supply duration (minutes)
V = total cylinder volume (liters)
p = initial charging pressure (psi)
s = low-pressure safety limit (psi)
f = surface-flow rate (lpm)

(7) The low-pressure safety limit is normally 20 percent of the cylinder pressure rating. This factor covers 10 percent for descent and 10 percent for contingency. If the cylinder rating is less than 2,000 psi, use a safety limit of 400 psi.

(8) As an example, calculate the duration for the following conditions:

(*a*) Cylinder volume: 6 liters (two 3-liter cylinders).

(*b*) Cylinder pressure rating: 2,650 psi (stamped on cylinders). Initial charge: 2,000 psi.

(*c*) Safety limit: 530 psi (20 percent of cylinder pressure rating).

(*d*) Surface-flow rate: 6 lpm.

(9) The calculation steps are—

(*a*) $t=\frac{(V)(p-s)}{(14.7)(f)}$

(*b*) $t=\frac{(6)(2000-530)}{(14.7)(6)}$

(*c*) $t=\frac{(6)(1470)}{(14.7)(6)}$

(*d*) $t=100$ minutes

3.6.8 USE

Preliminary Preparations

(1) Preliminary preparation of apparatus must always be conducted by qualified personnel. The instructions given here are general. For specific instructions always refer to the technical manual for the particular equipment (app. D).

(2) Make a thorough inspection of all equipment prior to use. Look for damaged and deteriorated equipment. Check tightness of all fittings in particular. Correct any leakage found.

(3) Charge cylinders with the predetermined gas or mixture. Observe all high-pressure-gas charging safety precautions. Specifically keep away from oils and open flames. Do not charge above the pressure rating stamped on a cylinder.

(4) Fill the canister with the absorbent specified for the apparatus.

(5) Set the flow. There are two ways to adjust flow: change of jet orifice and change of regulator pressure. In either case, the final measurement is the flow in liters of gas per minute. To measure the flow, install the flowmeter (which is supplied with the apparatus) into the injector circuit. Adjust the flow according to the requirements for the dive. For specific details regarding flow adjustments, refer to the technical manual for the particular equipment (app. D).

Predive Inspections

(6) If there is no checkoff list in the maintenance manual, the diving supervisor should prepare one to insure completion of all steps in preparation and inspection prior to entering the water.

(*a*) Following the preliminary preparations and unit charging of the apparatus, put on the apparatus and other associated accessories.

(*b*) Adjust the harness.

(*c*) Turn on and check all valves except the emergency cylinder valve.

(*d*) Upon entering the water, remain just under the surface until the buddy or tender ascertains that there are no leaks in the apparatus.

(*e*) Gas should escape from the exhaust valve at the end of exhalation. This flow of gas from the exhaust valve is normal and indicates that the flow regulator is operating.

The Dive

(7) When certain that the apparatus is working satisfactorily and when it is in all respects ready for the descent, indicate so to the diving supervisor and receive his approval prior to commencing the descent.

The Descent

(8) In descending, when using semi-closed-circuit scuba, remember that the gas flow is too small to prevent squeeze of the breathing bag. Supplement the flow by use of the bypass valve. Maintain a comfortable volume in the breathing bag. If necessary, feel the bag to determine its volume. Keep the bag inflated to about two-thirds' capacity. Do not descend faster than the breathing bag can inflate either automatically or manually. Upon reaching the working depth, adjust the exhaust valve to provide for comfortable breathing pressure without use of the bypass valve. At the end of any full exhalation, the exhaust valve should discharge a small amount of gas.

At Diving Depth

(9) While at diving depth, work normally. Avoid extreme exertion unless the flow of the apparatus was previously set for heavy work. If the gear was set for a nonswimming dive, never attempt to swim. Avoid fast descents or ascents for short distances.

(10) Keep a "mental eye" on the exhaust valve—it is your most reliable flow indicator. With steady breathing at a given depth, the valve should discharge a small, constant volume of gas at the end of every exhalation. (At greater depths, the actual volume is smaller.) With irregular breathing, the valve should operate at least every third or fourth breath. Every few minutes exhale fully. If the exhaust valve does not function at the end of exhalation, the flow has stopped altogether. If it discharges a much smaller volume than on previous checks at the same depth, the flow has fallen off. Check the low-flow warning device if there is one. Carry out emergency procedures for injector failure.

(11) Do not overstay the duration time for the apparatus. Surface personnel normally check the duration if communications are available. Make a separate check yourself, either by observing the gage on the apparatus or by timer. Always take the proper precautions when the dive may involve decompression.

(12) The decompression for nitrogen-oxygen mixture diving is always specified in terms of the stops necessary for a dive on air to the equivalent air depth. The stops may be tabulated for the depth on mixture, but they are basically those for an air dive to the equivalent depth. However, the use of a high-oxygen mixture as the breathing medium during decompression introduces a considerable safety factor in the

use of air stops since the procedure becomes a type of oxygen decompression.

The Ascent

(13) Diving with semi-closed-circuit scuba differs from diving with other scuba because of the long duration of the equipment, the depth, and the mixed gases. Decompression is quite often necessary. The rule for ascent is never to exceed the rate specified in current tables. Decompression for nitrogen-oxygen, mixed-gas diving uses equivalent air tables which provide the necessary information for reference to the Standard Air Decompression Table.

(14) Prior to commencing the ascent, flush the breathing bag by using the mixed-gas bypass (or emergency valve). Use the following rules:

(*a*) Take such a position that exhaust valve is above the bag.

(*b*) Take several deep breaths and then exhale normally.

(*c*) Open the exhaust valve and let water pressure flatten the bag out.

(*d*) Close the exhaust valve.

(*e*) Open the bypass (or emergency valve) and fill the bag to normal level. Do not leave this valve open long enough to exhaust any gas from the system.

(15) Commence the ascent and at 30 feet flush the breathing bag a second time. For this second flushing, use the following rules:

(*a*) If the only gas supply is mixed gas, flush the bag with the mixture at 30 feet. Then complete the ascent (including decompression as required). Use the main injection system for the rest of the ascent. Flush the system immediately before leaving each decompression stop.

(*b*) If the apparatus has an emergency supply of oxygen (not mixed gas), and if decompression is not required, turn off the main mixed-gas supply at 30 feet. Flush the system with oxygen and complete the ascent.

(*c*) If the apparatus has an emergency supply of oxygen (not mixed gas), but decompression is required, follow the procedure in item (*a*) above. Turn off the mixed-gas supply at 30 feet, then flush with oxygen instead of mixed gas immediately before leaving the 10-foot decompression stop.

Postdive Inspection

(16) The postdive inspection is exceptionally important because it is one of the best preventive measures that can be taken with any scuba equipment. Thoroughly cleanse the equipment of mud and foreign material with fresh water. Dump all absorbent and thoroughly clean the canister. Recheck the injector flow. If it has changed by more than 10 percent from the predive reading, examine the regulator and the filter. Correct the cause of the malfunction if it is found. Dry the equipment in the shade prior to stowage. The last diver using the equipment has the best working knowledge of how well it functioned. Log all comments from this diver. Take steps to investigate and repair any reported malfunctions. When sure that the equipment is in perfect working condition, prepare it for stowage. Talc all fabricated parts and use an approved preservative on rigid parts and fittings. Use the preservative sparingly. Keep it clear of all fabricated parts. Stow all parts in approved storage boxes or containers and keep in a cool, dry place.

3.6.9 MAINTENANCE

(1) Normally, if properly stored, the semiclosed apparatus requires very little general maintenance.

Gas Cylinders

(2) Clean and test the high-pressure cylinders (NAVSHIPS Inst. 9930.6).

Corrosion

(3) Inspect the apparatus at intervals of not more than 1 month. Check for corrosion of metallic parts and deterioration of fabricated parts. Represerve as necessary.

Gages

(4) Check gages associated with the apparatus quarterly for accuracy if in repeated use. If in stowage for more than one quarter, check prior to use and calibrate as necessary.

Gas-Metering Devices

(5) The gas-metering devices (jet and regulator) and the exhaust valve are the most sensitive elements of the semiclosed circuit. Keep them free of all foreign particles and corrosion.

Keep the strainers on the high-pressure side of the regulator clean of any foreign materials. Check them after each 10 hours of operation.

(6) Before diving in scuba where jet pressure can be determined, compare the pressure producing a standard flow with the rated pressure to produce that flow. If the pressure variation is excessive, clean the jet. The technical manual for the specific equipment gives allowable variations (app. D).

(7) In scuba which do not provide a check of the jet pressure gas for a given volume flow, clean the jet periodically after every 25 hours of operation.

(8) Keep the exhaust valve free from all corrosion. Overhaul it as often as necessary to insure positive operation. Clean the exhaust valve thoroughly after each dive to prevent the necessity for frequent overhaul.

Disassembly and Reassembly

(9) For disassembly, reassembly, and accurate readjustment of the apparatus, follow the instructions in the technical manual supplied with each unit (app. D).

SECTION 3.7 SAFETY PRECAUTIONS

3.7.1 GENERAL

(1) The development of self-contained diving has not in the least reduced the hazards of diving. In fact, it has increased the hazards. The nature of self-contained diving prevents the close supervision and the control that is possible with surface-supplied diving.

(2) Safety precautions for self-contained diving are intended to insure that personnel follow the safest procedures and principles when diving with scuba. The precautions for self-contained diving augment those for diving in general. Diving personnel are responsible for all the safety precautions given in part 1 as well as for those given here.

(3) Careful observation of applicable safety precaution can prevent the majority of diving accidents. However, some diving operations (particularly tactical operations) do not allow diving personnel to observe all safety precautions without exception. The diving supervisor must decide which safety precautions to disregard in a given situation, and he must be able to justify his decision on a basis of absolute necessity. He must then make sure that all personnel affected by his decision (a) realize the situation, (b) remain constantly alert to the hazard, and (c) know the applicable emergency procedure.

Personnel

(4) Except for trainees, only divers qualified in scuba diving should participate in self-contained diving operations.

(5) The diving supervisor should also be qualified in scuba diving.

Techniques

(6) Use the buddy system if at all possible, even for surface-tended dives.

(7) Use a buddy line in poor visibility.

Planning the Dive

(8) Survey the problem carefully.

(9) Choose suitable diving techniques.

(10) Select appropriate equipment.

(11) Observe applicable safety precautions.

(12) Brief the diving team thoroughly.

(13) Set up the operation as completely as possible.

Dressing for the Dive

(14) Wear the minimum equipment.

(15) Wear other accessories as compatible with safety.

(16) Use quick-release methods of attaching all releasable equipment.

(17) Use a lanyard on a separate face mask.

(18) Use a lanyard on the knife.

(*a*) Do not wear a knife on releasable equipment.

Making the Dive

(19) Enter the water carefully.

(20) Carry out the surface check.

(21) Swim down or pull yourself head first down the descending line.

(22) Extend hands ahead when swimming in poor visibility.

(23) Avoid overexertion.

(24) Breathe normally during ascent.

(25) Never wear earplugs.

(26) Never wear nonequalizing goggles.

Decompression

(27) Avoid decompression dives.

(28) Always follow standard procedures for decompression.

(29) Decompress for maximum depth attained on multilevel dives.

(30) Be prepared for cases of unplanned interrupted decompression.

Other Considerations

(31) Learn to dive without a face mask.

(32) Practice emergency procedures frequently to keep them ingrained in memory.

(33) Know the standard and special diving signals.

(34) Never ditch the scuba itself except as a last resort in dire emergency.

3.7.2 OPEN-CIRCUIT SCUBA

(1) Never charge the apparatus with oxygen.

(2) Always charge the apparatus with clean air from a known source.

(3) Charge the cylinders to the full pressure rating.

(4) Gage the cylinder pressure *immediately* before a dive.

(5) Do not dive without an adequate air-reserve mechanism.

3.7.3 CLOSED-CIRCUIT SCUBA

(1) Never charge the apparatus with any gas except oxygen.

(2) Always use fresh absorbent in the canister.

(3) Never use oil on the pressure fittings.

(4) Always purge air from the lungs and breathing system before starting a dive.

(5) Do not exceed the depth-time limits for pure oxygen.

3.7.4 SEMI-CLOSED-CIRCUIT SCUBA

(1) Always charge the apparatus with a standard mixture.

(2) Always use fresh absorbent in the canister.

(3) Carefully set the injector to the proper flow for the work anticipated.

(4) Do not exceed the maximum depth specified for the mixture in use.

(5) Be constantly alert for failure of the exhaust valve to bubble.

SECTION 3.8 EMERGENCY PROCEDURES

3.8.1 GENERAL

(1) Emergencies occasionally arise in the best planned and supervised scuba operations. Many of these emergencies are caused by failure of the diver to observe some safety precaution. Others are unforeseen or unavoidable. These emergencies can almost always be resolved if the diver, his buddy, his tender, or the diving supervisor stops to think. Take a second to reason the situation through to a solution. Do not act immediately on what may prove to be a blind impulse brought on by panic.

(2) Few situations in diving are so serious as to require instantaneous action. Remember your training and do not panic.

(3) Above all, never abandon the breathing apparatus under water unless you cannot ascend without doing so.

Emergency Ascent

(4) Except in the most desperate situations, make an emergency ascent by swimming to the surface. The possibility of becoming entangled or of striking an obstruction makes it hazardous to use positive buoyancy for ascent. Swimming to the surface gives a better chance to avoid entanglement and to clear obstructions. In some situations a large object overhead may preclude anything but swimming.

(5) An emergency situation can become so desperate that the need to surface outweighs the need for caution. If it becomes preferable to risk entanglement or injury rather than to remain on the bottom, inflate the lifejacket and ascend with the aid of its positive buoyancy. Bear in mind that the ascent will be very rapid. The danger of air embolism increases, and the possibility of serious injury upon striking an obstruction becomes very great.

(6) Use positive-buoyancy ascent only to resolve a life-or-death situation, and no other. Otherwise, swim to the surface.

(7) Whatever the means of ascent, exhale continuously throughout.

At the Surface

(8) Upon reaching the surface, inflate the lifejacket. Decide whether to take off the breathing apparatus or to leave it on while swimming to safety.

(9) An open-circuit scuba becomes very heavy when it breaks the surface. A closed-circuit scuba may hamper body motion. If the breathing apparatus interferes with swimming, remove the equipment and tow it to safety.

(10) A closed-circuit scuba can provide additional buoyancy. If it is desirable to take advantage of this characteristic, inflate the breathing bag to the fullest extent that still allows comfortable breathing. If the breathing medium is not usable, close the bag cutoff valves.

(11) Before removing a face mask, consider the hazards of unfavorable surface conditions such as whitecaps and spray.

Flooding of a Separate Face Mask

(12) Learn to dive without a face mask. Flooding of a separate face mask is then not a serious problem.

(13) To clear the face mask, use the following procedure:

(*a*) Tilt the head backward.

(*b*) Hold the upper part of the face mask tight across the forehead.

(*c*) Exhale through the nose. Water will drain past the lower edge of the face mask.

(14) Exhale occasionally through the nose to clear the face mask of small amounts of water. This procedure will also prevent face squeeze by equalizing pressure inside the face mask.

Flooding of a Full Face Mask

(15) Flooding of a full face mask is a serious problem, but every acceptable apparatus should have a means of overcoming it. The technique depends upon the type of apparatus used. The

diver should be thoroughly trained in the method peculiar to the apparatus he is using.

Flooding of the Breathing System

(16) The seriousness of flooding of the breathing system depends on the type of scuba used. In general it is less of a problem in open-circuit scuba.

(17) Be alert to the possibility that the cause of flooding (for example, a cut breathing tube) may prevent successful clearing of the system.

3.8.2 OPEN-CIRCUIT SCUBA

Exhaustion of the Air Supply

(1) Running out of air is not a serious situation unless the air-reserve mechanism has failed to function. Even in this case, the increase in breathing resistance prior to complete exhaustion of the air supply warns the diver.

(2) When the breathing resistance becomes noticeable, open the air-reserve valve and start the ascent.

(3) If opening the air-reserve valve does not restore a normal breathing supply, make an emergency ascent. During ascent, the reduction in water pressure provides at least a small amount of additional air unless the failure is mechanical.

(4) Continue to breathe normally throughout ascent, if possible. If not, exhale continuously throughout.

Buddy Breathing

(5) If during a dive there is a malfunction of the regulator or complete loss of the air supply, it may become necessary to buddy-breathe. Signal your buddy and let him know that you are in trouble and need his air supply. The buddy will give you his mouthpiece. *Never* take or grab it away from him. Once you have the mouthpiece in your mouth, begin to breathe. Remember that having the mouthpiece above the regulator will allow the regulator to free-flow and to give you air. Alternate breathing in this manner with your buddy. In any situation which requires buddy breathing, you must start ascent as soon as possible when the situation is under control. The cause of the malfunction can best be discovered once you reach the surface. You can swim to the surface exchanging the mouthpiece as often as needed. Remember that you must exhale continuously during the ascent when not breathing from the mouthpiece.

Clearing the Breathing System

(6) The proper technique for clearing depends on the specific open-circuit scuba used. Study the procedure in the technical manual and practice it frequently (app. D).

3.8.3 CLOSED-CIRCUIT SCUBA

Exhaustion of Gas Supply

(1) Exhaustion of the gas supply is not a serious problem. The oxygen in the breathing system is usually enough for several minutes of light swimming. Simply swim to the surface and shift to air breathing.

Clearing the Breathing System

(2) Flooding of the breathing system is usually serious. Most closed-circuit scuba do not provide for adequately clearing large amounts of water without thoroughly wetting the absorbent. Follow the procedure given in the technical manual.

(3) If there is no way to clear the water, make an emergency ascent.

3.8.4 SEMI-CLOSED-CIRCUIT SCUBA

Exhaustion of Gas Supply

(1) Exhaustion of the gas supply requires immediate action to avoid oxygen deficiency. The exact procedure depends on the specific scuba used and especially on availability of an emergency gas supply. Follow the procedure given in the instruction manual for the particular apparatus.

(2) After surfacing, shift immediately to air breathing.

Failure of the Injector

(3) If the injector fails, follow the technique for routine ascent if the bypass still works. Otherwise, follow the procedure for exhaustion of gas supply.

Clearing the Breathing System

(4) The problem of flooding the breathing system is the same in closed and semiclosed systems.

U.S. NAVY DIVING MANUAL

APPENDIX A

FIRST AID AND EMERGENCY PROCEDURES

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A-A. INTRODUCTION

First aid, as presented in this chapter, is concerned with management of wounds from either routine accidents or conventional weapons, and treatment of emergencies of a conventional nature which occur in any peace or wartime situation.

First aid, in any situation, consists of the emergency treatment of the sick and injured before medical or surgical attention can be obtained. Measures taken should neither supersede nor take the place of proper medical or surgical attention, and should consist of furnishing temporary assistance until competent medical aid is available.

The purposes of first aid are—

1. To save life.
2. To prevent further injury or unfavorable progression.
3. To preserve resistance and vitality.

A real knowledge of first aid and its purposes, when properly applied, may mean the difference between life and death, between rapid recovery and long hospitalization, between temporary disability and permanent injury.

Knowing when and how to apply first-aid measures for the many varied conditions that confront the diver requires extensive knowledge and a continual studious effort on his part to keep abreast with the changes in, and new concepts of, first-aid treatment.

General First-Aid Rules

The following rules should be observed:

1. Keep the patient lying down until the extent of the injuries is determined. However, it should be quickly noted if the patient has one of the following problems which represent exceptions to this rule and require a different position:

Severe shock.—If the casualty is in severe shock, place him in a supine position with his head and chest slightly lower than his feet.

Bleeding from or around mouth or nose, or vomiting, and semicomatose condition.—If the casualty is in danger of inhaling blood, vomit, or water—and this is especially dangerous if the cough reflex is missing and he is semicomatose—then place him in a prone position with his head lower than his feet.

Shortness of breath.—If the casualty has a chest injury, or has shortness of breath (dyspnea) due to pneumothorax, or respiratory obstruction, among others, place him in a sitting or semisitting position.

2. Examine the patient for hemorrhage, cessation of breathing, and traumatic shock—all of which are priority conditions. Hemorrhage and stoppage of breathing are both of such great immediate importance that, whenever possible, one person should take care of one condition while another person attends at once to the other.

3. Remove enough clothing to get a clear idea of the extent of the injury. It is preferable to rip the clothing along the seams, but the material may be cut if the ripping process is going to disturb the casualty unduly or aggravate an injury. Removing clothing in the usual way may do great harm, especially in fracture injuries. Do not remove so much clothing that the patient will become cold.

4. Keep the casualty reassured and as comfortable as possible.

5. Avoid allowing the casualty to see his injury. Assure him that his injuries are understood and that he will get good care.

6. Do not touch open wounds or burns with fingers or other objects except when sterile compresses or bandages are not available and it is imperative to stop severe bleeding.

7. Do not try to give an unconscious person any solid or liquid substance by mouth. He may vomit and get some of the material into the lungs when he breathes. Inhalation of vomit may cause pneumonia or lung abscess. Indeed, blockage of

the windpipe, strangulation, and death could result.

8. Do not move a casualty until the extent of his injuries has been determined and appropriate first-aid measures have been utilized to avoid increasing the damage already received. The simplest form of field methods may prove lifesaving in cases of severe bone fractures, for the jagged bone may otherwise precipitate hemorrhage and great soft tissue damage, and therefore increase shock. This is especially so if the casualty has to be transported through a long or difficult chain of evacuation before definitive treatment can be carried out. Any threat of fire, necessity to abandon ship, exposure to enemy gunfire, etc., may require suspension of this rule, but the principle should always be kept firmly in mind and weighed against these factors.

9. Always see that the litter patient is carried feet forward no matter what the nature of his injuries. This will enable the rear bearer to assess the condition of the casualty in transit and to observe immediately any respiratory obstruction or arrest.

Of all the demands made upon the diver assigned to first-aid duty, management of the seriously injured is the most exacting and requires all the independent judgment, courage, and energy that he can muster. The prime consideration is the survival of the casualty so that proper treatment can be performed at a sickbay or hospital properly staffed and equipped. The diver handling first-aid duties must decide whether the casualty can survive transportation to the hospital or whether immediate treatment is required for control of hemorrhage, asphyxia, shock and/or pain. These are grave emergencies and the following sections are devoted to proper methods of management and control.

Sorting of Casualties

Sorting (also known as triage) is the evaluation and classification of casualties for the purpose of establishing priorities for treatment and evacuation. Sorting decisions may vary greatly depending upon the tactical situation, and may occur at every stage in rearward movement of the wounded. The following discussion, however, refers primarily to the forward aid station or to the shipboard battle-dressing station.

Sorting for treatment.—Immediately upon arrival at an aid station, casualties should be sorted into the following treatment priority groups in the order listed, the highest priority being listed first:

1. Lightly injured: These are ambulatory casualties whose injuries are not disabling. During battle they must be cared for quickly so that they can return to duty immediately. Their treatment will not usually be time consuming and often may be delegated to others or even to the injured himself. When the actual fighting has ceased, these casualties descend to a lower order of priority.

2. Critically injured: Casualties in immediate danger from asphyxia, hemorrhage, or shock are the the ones who can be saved only by quick, efficient, and energetic care. Where lifesaving measures such as clearing an obstructed airway or arresting hemorrhage can be accomplished rapidly, such measures should be undertaken even under battle conditions.

3. The seriously injured: In these casualties the situation may be very grave but the urgency is not quite so immediate as those in category 2. Included would be gunshot wounds of the abdomen, tourniquet cases (hemorrhage controlled), chest injuries without respiratory failure, and other similar injuries which might require 3 to 4 hours of professional care.

4. The hopelessly injured: Relief of the pain and suffering of these casualties is all that is indicated. Time must not be expended on this group when it could be more effectively used on those who might die without immediate care. Included in this category would be the napalm victim with 60 percent or more of the body surface burned.

Sorting for evacuation.—Priorities must also be assigned to casualties for evacuation. In this sorting, priorities are controlled by the relative need of the casualty for special medical and surgical treatment. The decisions are affected by the type and duration of the required transportation and the ability of the casualty to withstand the type available, the tactical situation, the nature and workload of the receiving medical activity, and many other factors.

The following general order of priority for evacuation might apply in some situations, but requires much modification in others:

1. Chest and neck wounds with respiratory difficulty.
2. Chest or abdominal wounds with evidence of continued bleeding internally but with reasonable expectancy of safe arrival at a hospital.
3. Missile wounds of abdomen.
4. Tourniquet cases.
5. Head injuries.
6. Spinal-cord injuries (paraplegias).
7. Burns involving 20 to 50 percent of body surface.
8. Fractures of major bones.

Depending upon the effectiveness of the first aid, some otherwise high-priority casualty might be treated more safely at the site. The presence of a medical officer with adequate blood volume expanders and other supplies and equipment might radically change the list of priorities for evacuation.

Evacuation of Casualties

Shipboard casualties are evacuated to rear-base hospitals or to the medical facilities of large ships. Attack carriers and other large ships are staffed and fitted to care for numbers of sick and wounded. Helicopter landing ships and attack transports may have special surgical teams aboard.

It is always advisable to know as much as possible about the medical and surgical capabilities of other ships in the force. When emergency situations develop, information of this sort can be invaluable.

Fixed patterns of evacuation are not always possible because military tactical situations may change rapidly and weather conditions, distances involved, and nature of the wound all must be considered.

A–B. GENERAL PROCEDURES IN CARE OF WOUNDED AND INJURED

Before discussing care of wounded and injured, a word or two should be directed to a diver who may have the responsibility of sorting and establishing priorities of treatment for casualties. He should—

1. Keep calm, never permitting himself to become excited or confused.
2. Act quickly with efficiency and confidence, making his decisions on priorities as soon as possible.
3. In the event of mass casualties, enlist the aid of the not seriously wounded and injured to work under his direction in ministering to others. In this event, give his orders calmly with clarity and authority.
4. Understand and accept the concept of greatest good for greatest number. Many casualties in need of care must be turned away and sent back to man their stations, and others needing immediate care will have to wait. Also, many will have to be classified as so hopelessly injured that no time can be spent on them. These are painful decisions, but the diver with such duties must bear in mind that the success of his job is judged by the numbers of casualties who survive.

CONTROL OF HEMORRHAGE

Hemorrhage, or bleeding, is the escape of blood from arteries, veins, and even capillaries, because of a break in their walls. Control of active bleeding is an urgent matter.

Arterial bleeding from a major vessel can exsanguinate (drain of blood) a casualty in a very short time. Continued venous bleeding is not as apparent, but may be more deadly for this very reason. Identification of the source of bleeding may be made as follows:

Arterial hemorrhage.—Blood escaping is bright red, gushes forth in jets or spurts which are synchronized with the pulse.

Venous hemorrhage.—Blood is dark red and escapes in a steady flow.

Capillary hemorrhage.—Blood is intermediate in color, and oozes from the wound.

Hemorrhage may be brought about spontaneously (by straining, coughing, or rupture of diseased vessels) or it may result from trauma (by cutting with a sharp instrument such as shell fragments or steel plate, heavy blow of an object, or sharp end of a fractured bone).

The average adult body contains about 6 quarts of blood. One pint can usually be lost with no harmful effects (this is the average amount given by blood donors). The rapid loss of 1 quart of blood will produce certain symptoms, and the greater the loss, the more pronounced the symptoms. The loss of a quarter of the blood volume is dangerous and may be fatal.

Symptoms and Diagnosis

External hemorrhage can be seen and is easily recognized. Internal, or concealed, hemorrhage is difficult to diagnose. Concealed hemorrhage may result from puncture wounds; wounds that have been closed by sutures, especially deep wounds; heavy blows rupturing internal organs; spontaneous rupture of internal vessels; and numerous other causes. Symptoms of hemorrhage are easily confused with those of nonhemorrhagic shock.

The following symptoms are *usually* present. They are indicative of either external or internal hemorrhage, the degree depending upon the amount and rapidity of blood loss.

1. Pale skin or pale mucous membranes. Skin moist and clammy or waxy.
2. Temperature subnormal.
3. Pulse rate increased. Pulse feeble and easily compressible or lost.
4. Blood pressure lowered. Sometimes blood pressure is well maintained after the loss of a considerable amount of blood and then drops alarmingly after a small amount of additional loss.

5. Pupils of eyes dilated and slow in reacting to light or in accommodation. Remember morphine causes pupils to constrict. This must be considered if the casualty has been treated for pain.

6. Ringing in ears (tinnitus).

7. Faintness or actual fainting (syncope) may be the first symptom of internal hemorrhage.

8. Dehydration, frequent complaints of thirst.

9. Air hunger, often with yawning.

10. Impaired vision, especially in the erect or sitting position.

Management of Arterial Hemorrhage

Internal hemorrhage.—Severe, internal, arterial hemorrhage can be controlled only by surgery. Until the casualty reaches a hospital, he must be kept alive by transfusions of whole blood or by blood volume expanders which can be used as an expedient until blood can be obtained. Blood loss produces oligemic (hemorrhagic) shock. The treatment of oligemic shock is discussed under "Shock."

External hemorrhage.—In acute emergencies, as in severance of large arteries, prompt and decisive measures are essential. There are three measures to control such bleeding—local pressure, pressure at the pressure point between the wound and the heart, and the application of a tourniquet.

1. Local pressure is the method of choice in the vast majority of wounds where the bleeding is moderately severe. Local pressure is best applied by packing sterile compresses firmly into the wound and exerting continuous pressure against the compresses. The pressure is maintained until bleeding is controlled (see fig. A–1*A*). Snug bandages are then applied to keep the compresses in place (see fig. A–1*B*). Both the casualty and bandages should be carefully observed for signs of recurring bleeding. Restlessness on the part of the casualty may start the bleeding again, or sometimes bleeding starts when the blood pressure rises to normal levels.

2. Pressure on the pressure points will control arterial bleeding in the region supplied by that artery. Plate 1 should be carefully studied and the points where arteries can be compressed against bony surfaces should be committed to memory. Occasionally it may be necessary to compress the vessels distal to the wound also to control venous flow and blood from collateral arteries. Pressure points are especially helpful in controlling bleeding quickly and can serve as a stopgap measure if pressure compresses or a tourniquet must be located and readied for application.

3. A tourniquet is a constricting band which can be placed around an extremity and tightened until all arterial blood flow stops. Tourniquets supplied in field kits are either a length of rubber tubing or a webbed strap with a suitable buckle. However, a triangular bandage, webbed belt, or piece of line can be used. If a strip of rubber tubing is available, elevate the injured limb, and with the right hand wind the rubber tubing, under steady pull, around the limb. The first turn must overlap the end of the tubing to prevent it from slipping. The entire length is wrapped around the limb and the loose end is secured by anchoring under the next to last turn (see fig. A–2).

Whatever is used, a tourniquet should be only tight enough to arrest hemorrhage. If it is too tight it may cut through the skin or severely bruise muscles, nerves, and blood vessels. The limb below the tourniquet should take on a pale, yellowish tinge; the pulse in the limb beyond the tourniquet must disappear. If the tourniquet is too loose, it will produce a bluish congestion of the limb and increase bleeding because the blood will continue to flow into the limb through the arteries, but its return will

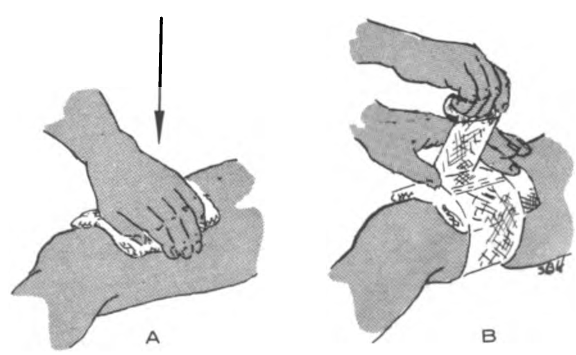
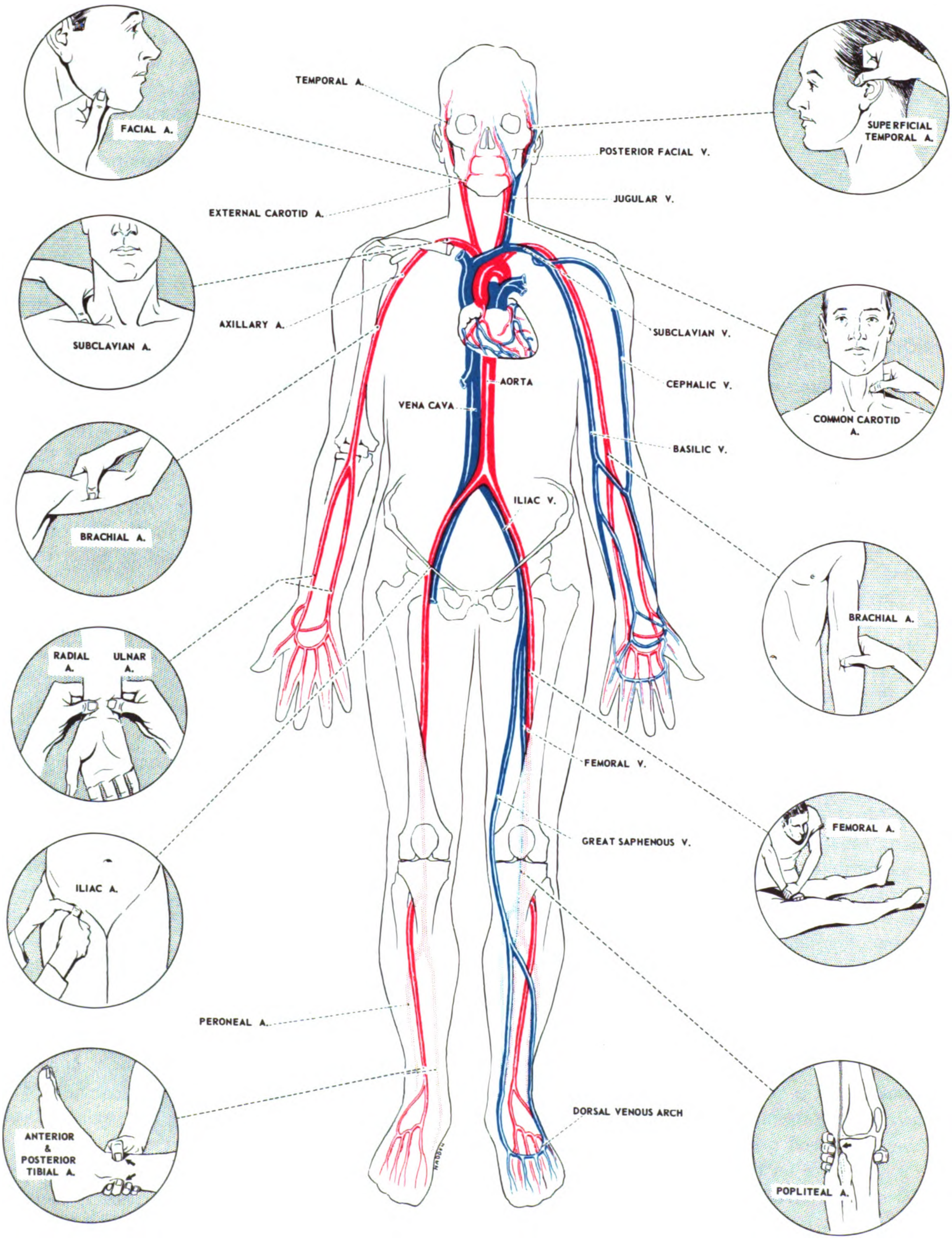


FIGURE A–1.—Direct pressure to control bleeding. A, direct hand pressure over bleeding point to control hemorrhage; B, application of snug bandage to maintain pressure.


TEMPORAL A.
FACIAL A.
SUPERFICIAL TEMPORAL A.
POSTERIOR FACIAL V.
JUGULAR V.
EXTERNAL CAROTID A.
SUBCLAVIAN A.
AXILLARY A.
SUBCLAVIAN V.
CEPHALIC V.
COMMON CAROTID A.
AORTA
VENA CAVA
BASILIC V.
BRACHIAL A.
ILIAC V.
BRACHIAL A.
RADIAL A.
ULNAR A.
FEMORAL V.
FEMORAL A.
GREAT SAPHENOUS V.
ILIAC A.
PERONEAL A.
DORSAL VENOUS ARCH
ANTERIOR & POSTERIOR TIBIAL A.
POPLITEAL A.

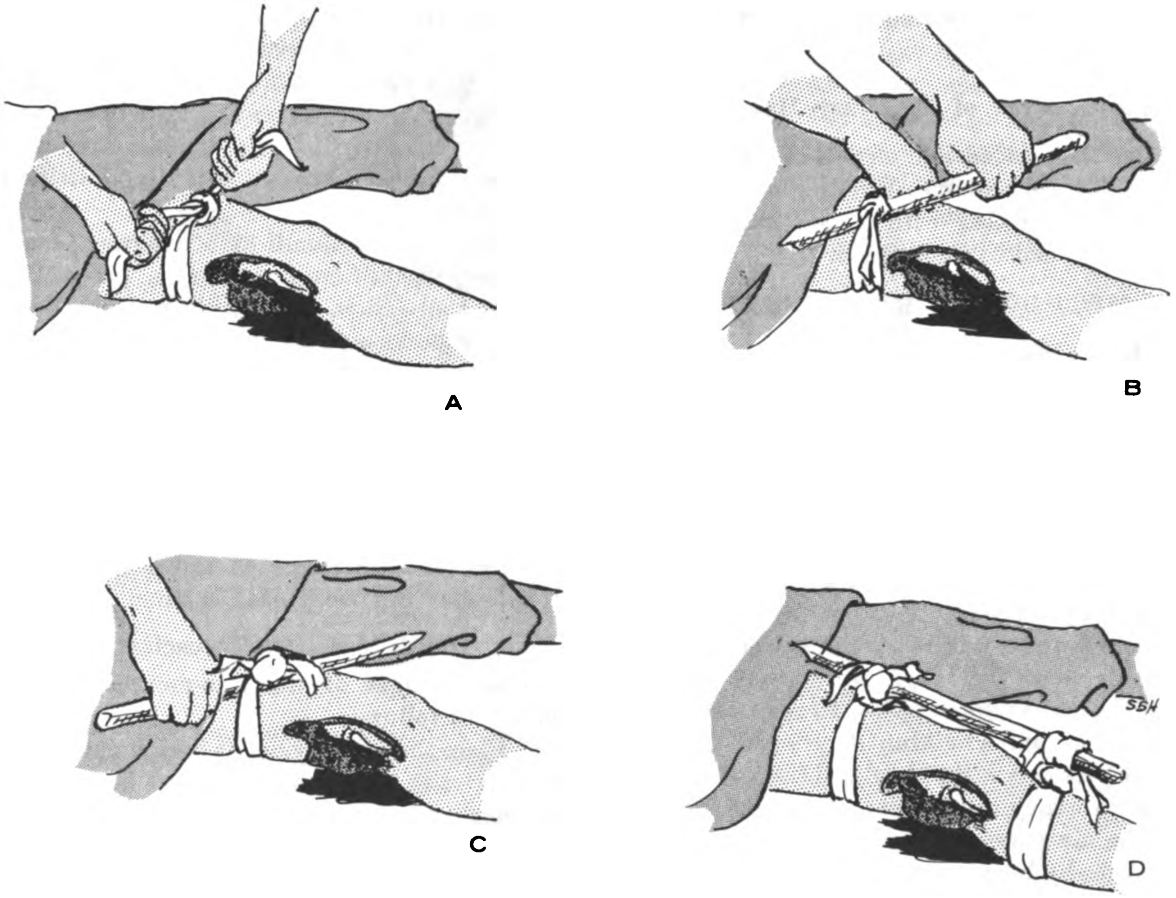


FIGURE A–2.—Application of improvised tourniquet. A, wrap a tie or handkerchief around the extremity and tie an overhead knot; B, put stick under knot; C, twist stick to tighten tourniquet; D, secure stick in position by tying another strip of material about extremity.

be interfered with because of compression of the veins.

The tourniquet should be left exposed to view and the letter "T" should be drawn on the casualty's forehead. A skin pencil, colored antiseptic, or ink can be used for this purpose. Once the tourniquet is in place, the casualty is put in the highest priority for evacuation. During evacuation the injured extremity should be elevated above heart level. Also, since the temperature of the bloodless extremity has much to do with the speed of tissue necrosis (death), it is wise to leave the extremity uncovered and never to use artificial means to warm it. Of course, in cold weather, care must be taken to prevent frostbite or other cold injuries.

The tourniquet should be loosened for 1 minute out of every 15 until the materials are at hand to control the hemorrhage by ligature or other means, and to restore the reduced blood volume by transfusions of blood or blood-volume expanders.

Management of Venous Hemorrhage

Venous hemorrhage can be identified by the dark-red color of the blood which is escaping in a steady flow. While it is not as demonstrative as arterial hemorrhage, its steady but insidious flow can be just as deadly if unchecked. Venous bleeding is almost always controllable by pressure. All that is usually necessary is the application of a dressing and a snug bandage over the dressing. In more profuse bleeding, the extremity may be snugly bandaged from toes or fingers up to the bleeding point after elevation of the part. This, with continued elevation, will stop the bleeding.

Management of Capillary Hemorrhage

Capillary blood is intermediate in color and oozes from the wound. Bleeding of this nature can be controlled with a compress dressing firmly applied with bandages.

METHODS OF RESUSCITATION

"Resuscitation" is a general term which covers all of the measures taken to restore life or consciousness to one apparently dead. These measures include *artificial respiration* to restore normal respiratory function, and *closed-chest cardiac massage* to restore normal heart beat.

Cessation of breathing (apnea) causes the condition known as asphyxia which is characterized by a failure of oxygen absorption *into* the lungs and a failure of elimination of carbon dioxide *from* the lungs. As a result, there is insufficient oxygen supplied to the body tissues (hypoxia), and a buildup of carbon dioxide and waste products at the blood and tissue-cell levels. Asphyxia may result from mechanical blockage of the air passage by water in drowning, by vomitus, by blood clots, and by foreign bodies; by swelling and increased secretions of mucous membranes following inhalation of live steam, smoke, or irritating gas. *Or*, it may result from paralysis of the respiratory muscles as in decompression sickness involving the spinal cord or brain; and from poisoning by gases such as carbon monoxide or the nerve gases. Lightning and electric shock may paralyze the respiratory center in the brain, or it may cause ventricular fibrillation, a form of irregularity of the heartbeat which is usually fatal.

There are several manual methods which for years have been accepted on a nationwide basis as the solution to asphyxia. In general, these methods fall into two classes: "Push-pull" (back-pressure-armlift, back-pressure-hip-lift, chest-pressure-armlift), and rocking (Eve rocking method and variations on the rocking principle). All too frequently, however, these methods are not effective because of failure on the part of the operator to *maintain a free and unobstructed airway*. In fact, inherent in the method most frequently recommended, the back-pressure–armlift, is the occlusion of the airway by the head as it flexes when the arms are lifted. In addition, these methods have another basic flaw: there is no way for the operator to know whether or not the airway is open or blocked while actively rendering artificial respiration.

In recent years, mouth-to-mouth resuscitation has been received enthusiastically. The method was first advocated for infants and small children, but because of its great success in this age group, it came to be increasingly advocated for adults. As a result of the interest generated, studies were undertaken to evaluate the various methods of emergency artificial respiration. These studies indicated the superiority of mouth-to-mouth resuscitation over all manual methods in all age groups and body weights. Now, it is the recognized method of choice.

Mouth-to-Mouth Resuscitation

The technique of mouth-to-mouth resuscitation is as follows:

1. Place the casualty on his back immediately. Do not waste time moving him to a better place, loosening clothing, or draining water from lungs.

2. Quickly clear mouth and throat. Remove any dentures, mucus, food, and other obstructions.

3. Tilt head back as far as possible. The head should be in a "chin-up" or "sniff" position and the neck stretched (fig. A–3*A* and *B*).

4. Lift lower jaw forward. Grasp jaw by placing thumb into corner of mouth. Do not hold or depress tongue.

5. Pinch nose shut (or seal mouth). Prevent air leakage.

6. Open your mouth wide and blow. Take a deep breath and blow forcefully (except for babies) into mouth or nose until you see chest rise (fig. A–3*C* and *D*).

7. Listen for exhalation. Quickly remove your mouth when chest rises. The jaw is not high enough if victim makes snoring or gurgling sounds (fig. A–3*E*).

8. Repeat (6 and 7) 15 to 20 times per minute. Continue until victim begins to breathe normally.

9. Remove air blown into victim's stomach. Periodically, between breaths, if the stomach

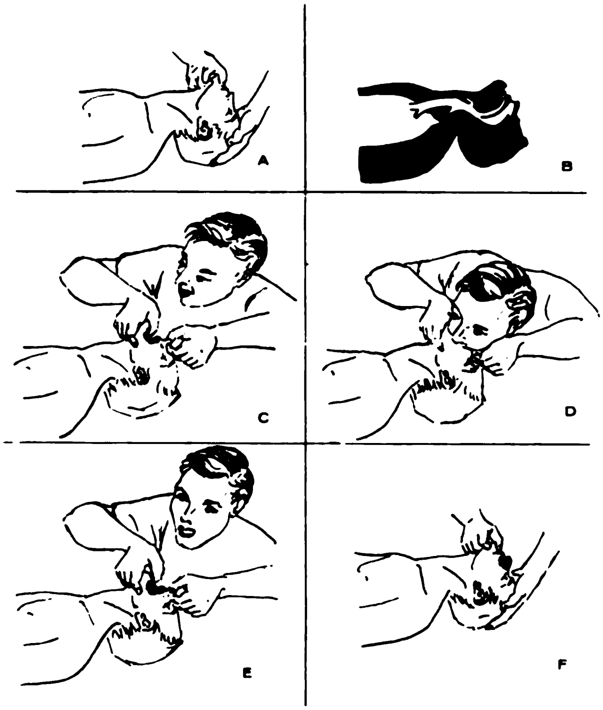


Figure A–3.—Mouth-to-mouth resuscitation. A, position of head and neck in hypertension; B, diagram of air passageway with neck in correct position; C and D, mouth-to-mouth breathing, rescuer breathes into victim's mouth; E, victim exhales and chest falls, rescuer inhales; F, position for mouth-to-nose breathing.

is distended, place the hand on the upper abdomen and gently but firmly press the air out of the stomach.

10. For infants seal both mouth and nose with your mouth. Blow with small puffs of air from your cheeks.

It should be stressed that resuscitation should be started immediately; i.e., before the heart stops and irreversible damage is done to the central nervous system. In drowning, for example, the rescuer should not attempt to remove the water which is frequently swallowed in large amounts. He should place the victim in a supine position and start mouth-to-mouth breathing promptly.

Esthetically, mouth-to-mouth resuscitation is objectionable to many. There is a hesitancy on the part of the rescuer to touch his mouth with the mouth of a moribund patient. Several solutions have been offered. The first one is to cover the victim's mouth with gauze or any clean cloth before blowing into his mouth (see fig. A–4*A*). This will prevent the lip-to-lip contact which is so obnoxious. For another, a ring may be formed with the index finger and thumb of the hand holding the victim's chin. The victim's lips are then opened and the ring placed firmly about his mouth thus holding his mouth open. The third and fourth fingers are placed under the victim's chin to maintain upward traction and the thumb seals off the nostrils (see fig. A–4*B* and *C*). The ring thus formed will make an effective seal with the rescuer's mouth, and lip-to-lip contact is thus avoided. A device known as an oropharyngeal airway (see fig. A–4*D* and *E*) also eliminates this objection; however, as with most first-aid devices, they are often not at hand when needed (see below for discussion).

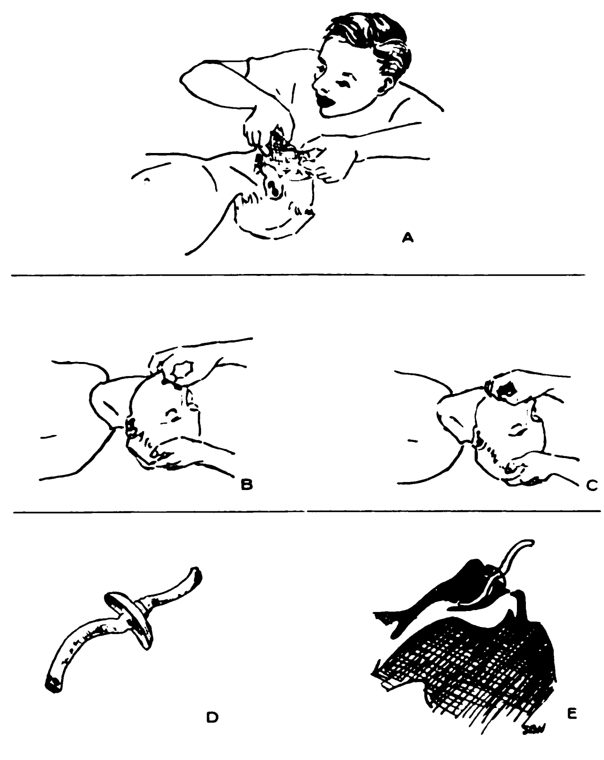


Figure A–4.—Methods of overcoming physical contact in mouth-to-mouth resuscitation. A, gauze or other porous, clean material placed over victim's lips; B, formation of finger ring—note that other fingers maintain the upward pull on the chin; C, finger ring in place forms an effective seal—note that thumb occludes the nostrils; D, oropharyngeal airway; E, diagrammatic sketch showing correct position of breathing tube.

NOTE

In mouth-to-mouth resuscitation, many unpleasant events may take place and must be triumphed over. For example, convulsions may develop during acute asphyxia or appear as a postanoxic sequel. During the seizures, spasms of the jaw muscles can inflict painful bites to the rescuer. Vomiting frequently occurs during recovery from hypoxia, and water can be expected to spurt from the mouths of drowning victims when air is delivered to their lungs. Mouth-to-nose ventilation can be used effectively during the convulsive state (fig. A-3*F*); the finger-ring technique makes resuscitating the vomiting victim less repulsive to fastidious rescuers. The act of saving a life regardless of unpleasantness is an important psychological aid in overcoming these obstacles.

Mouth-to-Airway Artificial Respiration

The oropharyngeal airway, an item of issue, eliminates the physical-contact element from mouth-to-mouth breathing which has proved to be objectionable to many rescuers. This S-shaped instrument is a combination of two sizes of oropharyngeal airways merged in continuity. One-half (the short half) serves as a mouthpiece for the rescuer; the other half is inserted into the victim's mouth, following along the curve of the tongue. In inserting this instrument, the operator should be careful not to push the tongue back but to hold it forward. When in position, the airtube can deliver the expired air of the rescuer directly into the pharynx, trachea, and lungs of the victim.

After the device has been placed properly, the rescuer should assume a position at the top of the victim's head, firmly grasp the lower jaw with both hands and pull forcefully upward. This position must be maintained throughout the procedure to maintain an open airway. The operator prevents leakage of air by occluding the patient's nose with his thumbs. (See fig. A-4*C* for proper positioning.)

The operator then proceeds to inflate the victim's lungs by blowing into the mouthpiece—forcefully with adults, gently with children, and only "puffs" with infants. (In resuscitation of small children and infants, the short end of the airtube should be inserted and the operator should blow through the long or larger end of the S-curved tube.)

The operator must watch the victim's chest constantly. When he sees the chest rise, he must remove his mouth from the mouthpiece and permit the victim to exhale passively by the natural elastic recoil of the lungs and the chest wall. For lung ventilation rate, see step 8 of the procedure for mouth-to-mouth resuscitation.

CAUTION

With the airway in place, the victim will gag and vomit when starting to respond to resuscitation efforts. At the first sign of revival, remove the airway.

Manual Methods of Artificial Respiration

Under certain circumstances, mouth-to-mouth resuscitation cannot be employed. The gas mask worn in contaminated areas would preclude its employment, as would maxillofacial injuries involving bleeding around the mouth and lips.

The efficacy of any method of artificial respiration, whether mouth-to-mouth or manual, depends upon a patent or open airway. Even with the oropharyngeal airway in place, exchange of air is facilitated only *if* the head is properly positioned. In utilizing the manual methods listed below, therefore, the first consideration must be proper positioning of the head to avoid any airway obstruction.

Back-pressure–armlift method.—Prior to the revival of mouth-to-mouth resuscitation, the back-pressure–armlift method was accepted on a nationwide basis as the one of choice (see fig. A-5). However, this method is doomed to fail in the overwhelming majority of cases because the head drops as the arms are raised, and this action shuts off the airway. If, however, an assistant is available to hold the victim's head up and thus maintain an open airway, then the back-pressure–armlift method becomes an effective resuscitative measure and the one of choice in those instances where drainage of fluids (cerebrospinal fluid, vomit) is troublesome, or

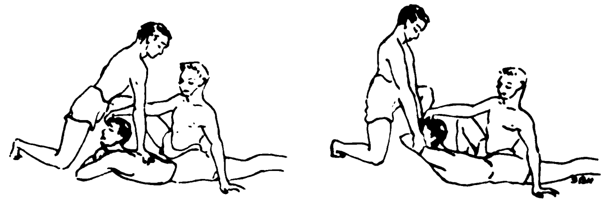


FIGURE A-5.—Back-pressure–armlift method, showing positioning of a two-man team.

if trauma with accompanying bleeding rules out mouth-to-mouth resuscitation.

The assistant should sit at one side of the victim's body facing toward his head, place his hand on the victim's forehead and, utilizing the ridge about the orbital cavities to secure a firm grasp, tilt the head backward. With his other arm, he supports his own body. The rescuer kneels at the victim's head on one or both knees, and faces toward his feet.

Step-by-step procedure is as follows:

1. Place hands on victim's back in such a way that the heels of the hands lie just below a line running between the armpits. With the tips of the thumbs touching, spread fingers.
2. Rock forward until arms are approximately vertical and allow the weight of the upper part of the body to exert slow, steady pressure downward on the hands. This forces air out of the lungs. Elbows should be kept straight and pressure exerted almost directly downward on the back.
3. Release the pressure, avoiding a final thrust, and commence to rock slowly backward.
4. Place hands upon victim's arms just above his elbows and draw his arms upward and backward. Apply just enough lift to feel resistance and tension at the victim's shoulders. Do not bend the elbows. With the backward rock the victim's arms will be drawn backward. Then drop the arms gently to the ground. This completes the full cycle.
5. Repeat steps 1 through 4 approximately 20 times per minute. As soon as the victim is breathing, adjust timing to assist him. Do not fight his attempts to breathe; synchronize your efforts with his.

Chest-pressure–armlift method.—As in other resuscitative methods, the key to success is in a patent airway. If an assistant is not available, a blanket, pillow, folded coat, or the like may be used to elevate the shoulders and hyperextend the neck (see fig. A–6*B*). Or, the operator may place one foot under the victim's shoulder and thus elevate his shoulders. Then by tilting his head backward and pressing firmly with a knee against the top, he can maintain the head in this position (see fig. A–6*A*).

To ventilate the lungs the operator grasps the victim's forearms above the wrists. He places the victim's hands on his chest, rocks forward, and exerts moderate pressure almost vertically downward until he feels firm resistance. The operator then rocks backward, drawing the victim's arms upward and backward. The chest pressure produces active expiration and the armlift stretches the chest muscles to produce active inspiration.

FIGURE A–6.—Chest-pressure–armlift, one-man methods. A, arrow points to left foot under victim's shoulders, causing head to tilt backward, and right knee presses against top of head, maintaining tilted position; B, folded blanket or coat placed under shoulders tilts head backward to open airway.

Back-pressure–hip-lift method.—The victim should be placed in a prone position with his neck hyperextended (fig. A–7). The operator kneels on one knee at the level of the casualty's hips. He rocks forward and places his hands over the midback with his fingers spread and the thumbs touching the spine. Moderate pressure is then exerted almost vertically downward until he feels firm resistance. He then rocks backward and places his hands under the victim's hips. Keeping his arms straight, the operator lifts the hips about 6 inches off the ground. This cycle is repeated about 20 times per minute.

This maneuver is often difficult to perform for long periods especially if the victim is large or heavy. It does have one advantage, however, in that each time the hips are lifted, the body is pulled away from the face and this tends to keep the neck extended.

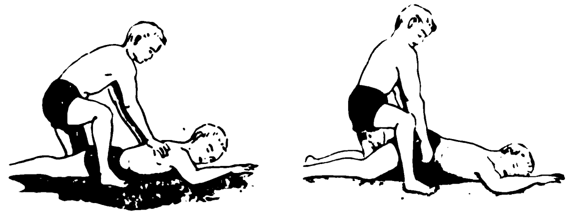


FIGURE A–7.—Back-pressure hip lift.

Mechanical Resuscitation

Several kinds of portable resuscitator-inhalator-aspirator units (complete with adult and child-size masks and airways, capable of applying intermittent positive and negative pressure, with automatic cycling) are available for issue or purchase. None of the aforementioned methods of artificial respiration can replace this efficient instrument; however, all too frequently one is not located near the scene of the accident and other means must be found to revive the casualty.

Positioning of the victim is not so vital in this as in other methods, and for this reason it is particularly suited to situations in which the casualty is trapped by a falling object or pinned in a poorly accessible place. An extension hose permits the operator to work in tight places and at a distance of 25 feet from the oxygen tank.

The mechanical resuscitator is a multipurpose instrument serving as *resuscitator* (when there is no breathing or when breathing is difficult, slow, or shallow as in patients with asthma); as *inhalator* (when more oxygen than is normally required is needed as in patients in shock, with varying heart conditions or lung-tissue damage caused by irritating fumes or gases); as *aspirator* (to clear the airway of blood or mucus).

The resuscitator is a lifesaving instrument and should be very carefully inspected and maintained. It should be tested at least once a month. This does not mean only to open the case and look inside. The machine should be assembled and run for a minute or two, and the pressure gage should be checked at this time to be sure there is an adequate supply of oxygen.

The booklet of instruction should be kept in the holder provided in the lid of the carrying case. Every diver should study the booklet of instruction on the operation and care of the resuscitator so that he can operate it at a moment's notice.

Closed-Chest Cardiac Massage

Cardiac arrest may be caused by lightning and electric shock, or it may result from a period of asphyxia and hypoxia. It may also be produced by several causes working together such as hypoxia (reduction of oxygen in body tissues below physiologic levels), anemia, shock, and myocardial (heart muscle) exhaustion. There are many other causes as well.

For many years, cardiac standstill was treated by opening the chest surgically and massaging the heart. In recent years, a method of massage has been developed in which the chest is not opened. In this method the heart is squeezed by pressing on the breastbone. This provides adequate circulation to nourish the central nervous system and maintain the tone of the heart. Since asphyxia and hypoxia accompany cardiac standstill, it is recommended that the lungs be ventilated at the same time. Mouth-to-mouth resuscitation may be employed or, if available, 100 percent oxygen may be administered by intermittent positive pressure. The latter method is preferred.

All divers should be thoroughly familiar with this method of restarting heart action, for it can be employed effectively aboard ship, or in the field. When properly performed, closed-chest cardiac massage will provide adequate circulation to protect the brain, heart, kidneys, and other vital organs and will either result in a spontaneous resumption of heartbeat or allow time to get the casualty to a defibrillator (a device to reestablish the heart's rhythm).

NOTE

Steps to revive halted hearts must begin within 4 minutes after the heart stops beating. Damage to the brain and other organs is too great beyond this time limit.

Technique of closed-chest cardiac massage

1. Place the patient in an outstretched position on his back, preferably on a hard surface such as the floor. Hold the head back in order to keep the airway unobstructed.

2. Kneel at right angles to the patient and locate the upper and lower ends of the breastbone.

3. Place the heel of one hand on the lower one-third of the breastbone. Place the heel of the other hand on top of it (fig. A–8*A*).

4. Press vertically downward, using some of the weight of the body, until the breastbone is depressed about 1½ inches (see fig. A–8*B*). Then release the pressure with the hands lifted slightly. This procedure is repeated 60 to 80

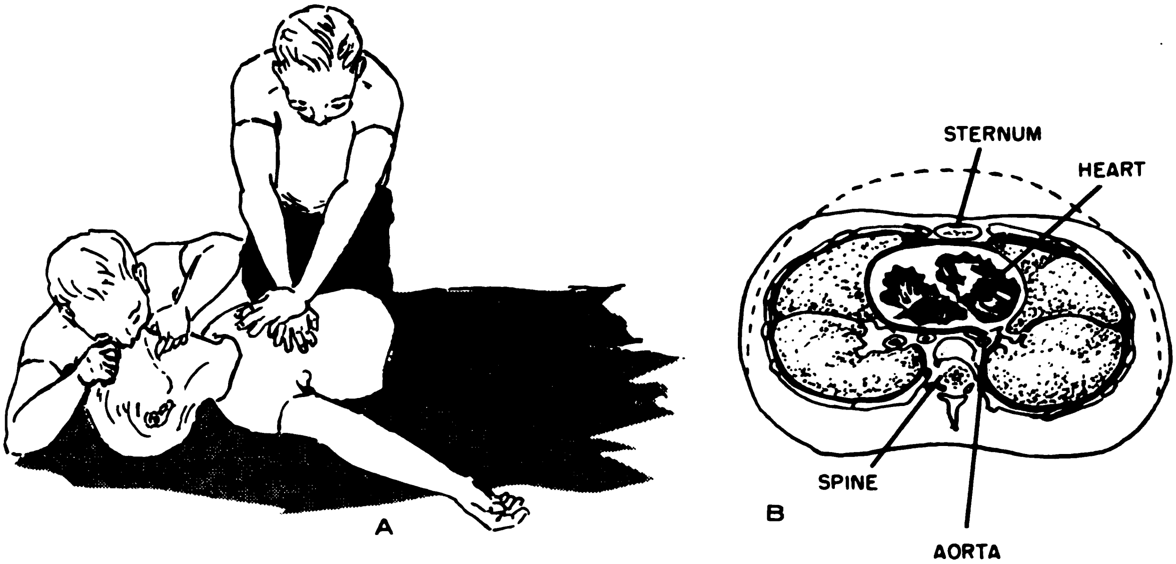


FIGURE A–8.—Closed-chest cardiac massage combined with mouth-to-mouth resuscitation. A, area to apply chest pressure; B, cross section of chest: dotted lines indicate relaxed chest, solid lines indicate depressed chest.

times per minute. No pressure should be applied with the fingers.

5. Concomitant artificial respiration should always be given. Enlist the aid of a bystander to give mouth-to-mouth resuscitation. If no one is available, massage the heart for 30 seconds and stop and give three or four rapid mouth-to-mouth artificial respirations. Then return to cardiac massage and continue in this pattern.

6. Observe for return of spontaneous cardiac action every 3 minutes. Evidence includes constriction of pupils, spontaneous respirations, and pulse.

With return of "life," the resuscitation procedures may stop at any step. Usually the return of spontaneous cardiac activity occurs in 5 to 20 minutes. If no means are available to get the casualty to a hospital or hospital equipment to him, efforts to revive him may be considered as unsuccessful and resuscitation measures stopped after the 20- to 30-minute point. Beyond this limit, hypoxic injury may be considered to have taken place.

MANAGEMENT OF SHOCK

Shock is a state of circulatory deficiency associated with depression of the vital processes of the body. There are several types of shock including oligemic, neurogenic, toxic or bacterial shock; also, shock of cardiorespiratory origin and anaphylactic shock. These types of shock may be present to varying degrees in the same patient. Unless otherwise stated, the word "shock" generally refers to oligemic shock (wound shock), the most frequently encountered and most important type for military personnel to understand.

Oligemic Shock

This condition is also known as secondary, delayed, surgical, traumatic, or wound shock. Burn shock and the shock of hemorrhage are varieties. The essential feature is a diminished volume of circulating blood (oligemia). Oligemia may be produced by—

1. Direct loss of blood as in external or internal hemorrhage.

2. Loss of plasma of the blood by seepage into tissues at the site of burns, contusions, and crush injuries.

3. Loss of fluids and electrolytes (sodium, potassium, chlorides, etc.) from the intestinal tract in severe vomiting, diarrhea, or intestinal fistula. This loss dehydrates the body and contracts the circulating blood volume as well.

As an example it has been estimated that in a fracture of the femoral shaft, there is a loss of 800 to 1,200 milliliters (1,000 milliliters equals 1.06 quarts) from the volume of circulating blood. A part of this loss is from hemorrhage into surrounding tissues and a part is from seepage and loss of plasma and electrolytes into the traumatized soft tissues around the fracture.

It should be noted that in shock due to hemorrhage, there is a loss of whole blood including red cells and that the body tends to restore circulating blood volume by supplying fluid to the circulation from the tissues. On the other hand, early burn shock leads to hemoconcentration from loss of the plasma fraction of the blood. In shock occurring in severe diarrhea, the loss is primarily in the water and electrolytes of the blood. In all of these conditions there is shock and the common factor is loss of circulating volume.

Wound shock and hemorrhagic shock may be seen frequently among casualties. Its early and effective treatment will save lives. It is therefore a subject of great importance to divers.

In shock, the diminished blood volume causes a markedly lessened cardiac output and reduced peripheral circulation. This results in a lowered transport of oxygen to the tissues (hypoxia) and a lowered transport of waste products away from the tissue cells. The tissue cells in turn react by developing an abnormal metabolism with an increased production of abnormal waste products, and a severe metabolic crisis ensues.

Early shock, even though very severe, is comparatively easy to treat successfully. But as tissue hypoxia develops and the process moves toward irreversibility, it becomes progressively more difficult to obtain recovery in spite of intensive treatment. Whenever the blood pressure drops below a certain level, usually between 60 and 80 systolic, the kidneys become unable to produce urine. If hypotension of this degree exists for longer than a brief period, renal shutdown may continue after the blood pressure is returned to normal levels. This is a fatal complication unless, of course, there is a later return of urine formation.

Prolonged shock can also cause serious, temporary, or permanent effects on the brain, heart muscle, and liver. Knowledge of the pathologic genesis of shock will enable the diver to understand the importance of early effective treatment before tissue hypoxia, renal shutdown, myocardial failure, or brain damage result.

Signs and symptoms

Shock should be expected in all casualties who have had gross hemorrhage; abdominal or chest wounds of any type; crush injuries (including underwater blasts); large muscle damage particularly of the extremities; all major fractures both closed and open (simple and compound); traumatic amputations from blasts, gunfire, and shell fragments; any head injury; burns involving more than 10 percent of the total body surface (see "Burns" under "Heat Injuries" below); or any severe wound found anywhere in the body.

The shock syndrome (set of symptoms which occur together) is variable and the symptoms listed below do not appear in every patient nor are they equally prominent (fig. A–9). For example, hyperexcitability may replace apathy in item 9 below.

Evaluation of the situation, according to the extent and severity of the injuries, is more important than any one particular sign or symp-

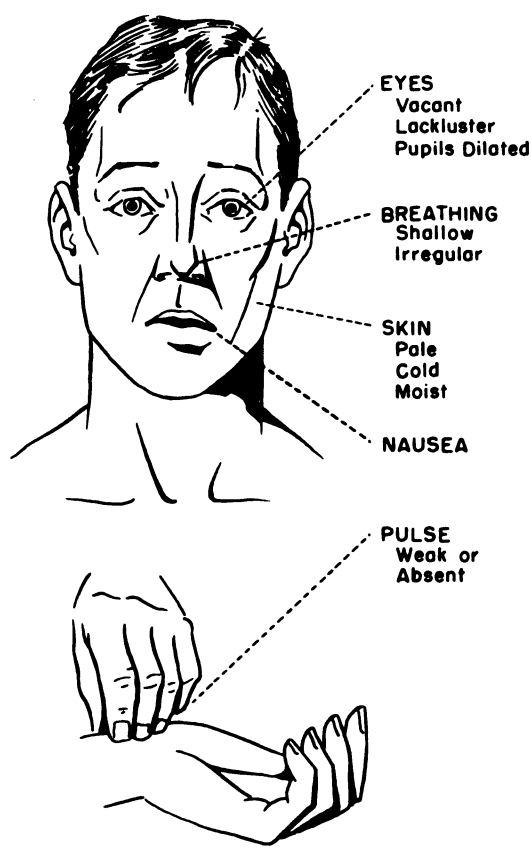


FIGURE A–9.—Symptoms of shock.

tom. It is important to start shock treatment before the characteristic symptoms develop. The following findings are representative of the varied picture which may be presented by the casualty in shock:

1. Eyes may be glassy, lackluster, have dilated pupils (unless morphine has been given), or suggest fear and apprehension.

2. Breathing may be normal, rapid, or labored, and of the "air hunger" type. In the advanced stages of shock, the breathing becomes shallow and irregular.

3. The lips may be pale or cyanotic (bluish gray).

4. The skin may be very pale or a peculiar ashen gray; in the dark complexioned, pale mucous membranes help identify the shock victim.

5. The skin temperature may be lowered and the body covered with clammy sweat. The temperature of the hands and feet, nose and ears, may provide some index of the circulation through the skin. In general, in shock due to trauma or hemorrhage, or both, the coolness of these areas is related to the decrease in peripheral circulation.

6. The pulse may be nearly normal or it may be rapid, weak, thready, and of poor volume. It is difficult and often impossible to feel the pulse in patients with severe lowering of the blood pressure. The pulse rate in oligemic shock is increased and may reach 140 or even higher, while the pulse rate in neurogenic shock is slowed often to 60 or even 40 (see "Neurogenic Shock" below).

7. The blood pressure usually falls in shock. A moderately severe shock will show a systolic pressure falling below 100 while simultaneously the pulse rises to above 100. The body compensates for blood loss by peripheral vasoconstriction. This process tends to maintain the blood pressure at nearly a normal level despite moderately severe loss of circulating blood volume. A point comes, however, when decompensation occurs and a very small additional loss will then produce an alarming and sudden fall in blood pressure.

8. There may be retching, nausea, vomiting, hiccups, and dryness of mouth, lips, and tongue.

9. Restlessness, apprehension, and then apathy are usual symptoms.

10. Skin veins collapse. Veins normally visible at the front of the elbow, on forearms and back of the hands, may become invisible or almost so.

11. Frequent complaints of thirst can occur. Shock victims may complain of thirst rather than pain, even though severely wounded.

12. The kidneys may shut down and urine formation either cease or become greatly diminished if the systolic blood pressure remains below 70 for long periods. This may occur early or appear later in the course of shock.

It is easy to recognize the fully developed picture of shock, but it is not so easy to recognize the patient about to go into shock. If effective preventive treatment is to be given, early recognition is of the greatest importance.

The inability of the individual to compensate for changes in position is one of the earlier signs to look for. If a patient lying down loses 750 or even 1,000 milliliters of blood, he often shows no change; yet, if he attempts to stand, sit up, or shift position, abnormal responses in blood pressure and pulse or even fainting may occur. In any event, the casualty should be closely observed for any of these signs when his position is altered in the process of giving first-aid treatment.

Treatment

In oligemic shock, the most important single requirement is to arrest and reverse progressive deterioration by prompt and adequate restoration of the circulatory volume of blood. Only when the circulating volume has been restored can improvement in tissue metabolism and recovery from shock be expected. Before discussing establishment of a competent circulation through fluid replacement, however, there are certain general measures which should be applied to all patients in shock.

General measures.—It is generally agreed that if pain is present its alleviation is an important part of the treatment of shock (see "Relief of Pain").

Patients in shock should be kept in a supine position. If shock is plainly evident, keep the head of the litter 12 inches lower than the foot of the litter. If blood pressure is normal, chest- or head-injury casualties should be positioned with the head slightly elevated. If face, jaw, mouth, or throat injuries produce bleeding into the pharynx, it is imperative that the patient be placed in a prone position with the head turned toward one side and with the head of the stretcher lowered ½ to 1 foot to avoid aspiration of blood and mucus into the lungs.

Prior to moving the patient, all wounds should be bandaged (see "Bandages and Bandaging") to prevent further wound contamination, and all fractures should be splinted (see "Fractures" under "Injuries to Muscles, Joints, and Bones," and also "Splints") to avoid further damage to tissues by the motion of the jagged bone in and around the fracture site. This will prevent additional shock being superimposed on the shock already existing, prevent new hemorrhage, put damaged tissues at rest, and increase the chances of success in later definitive surgical operations.

Body heat should be conserved in all casualties. Wet clothing should be removed and dry covering provided. The casualty in shock usually feels cold as a result of decreased peripheral circulation. Blankets or any dry material, loosely applied, are indicated; artificial means of warming (hot bricks, water bottles) are not indicated routinely because it encourages the undesirable dilatation of surface vessels and may cause a further depletion of blood fluids through sweating and, of course, the warming agents may burn the casualty.

The diver may be called upon to treat oligemic shock due to hemorrhage or injury. Under these circumstances the patient should receive solutions by mouth, provided he is conscious and able to swallow without difficulty. A satisfactory solution may be made by adding one level teaspoonful of salt and, if possible, one-half a teaspoonful of soda to a quart of water. Give this solution in small amounts until the patient's thirst is satisfied and one or more pints have been given.

This emergency replacement treatment can be carried out while the patient is being evacuated. At the hospital whole blood may be administered by the medical officer.

If during the course of replacement therapy the pulse and blood pressure return to normal, no more fluid should be administered. A careful watch for these vital signs is then kept, with readings every 15 minutes recommended.

Neurogenic Shock

Neurogenic shock, sometimes called vasovagal shock, results from nerve stimulation of the autonomic nervous system (the system which controls the viscera or internal organs, heart, blood vessels, smooth muscles, and glands). This stimulation brings about widespread vasodilatation (increased caliber of vessels and capillaries). Thus, after painful injury, an emotional upset, or psychic disturbance as that induced by fear or horror, the blood leaves the active circulation because of this dilatation and pools in the voluntary muscular system and in the gastrointestinal system. This effect reduces the volume in actual circulation and the cardiac output drops. This is the usual cause of syncope. Fortunately, the reflex action is usually only temporary.

Symptoms and signs

Neurogenic shock may be manifested by yawning, fainting, vomiting, sweating, pallor, waning of consciousness, decrease of pulse rate to 60 or below, a fall of systolic blood pressure, sometimes to 50 millimeters of mercury, and deep, sighing respiration. The typical syncopal reaction is distinguished from oligemic shock by sudden onset, slow pulse, and rapid recovery.

Treatment

Simple fainting, the mild variety of neurogenic shock, can be adequately treated by placing the patient in a supine or prone position with the head and chest slightly lower than the feet. Constrictive clothing should be loosened. A few whiffs of ammonia may be given and may prove helpful. A sitting patient may often be relieved by having him bend forward and place his head between his knees. A deep breath followed by a cough may help to restore cerebral circulation, or circulation may be restored by placing a hand behind the patient's head and having him make upward pressure against it. In severe syncope, the subject may display convulsive movements as a result of absence of cerebral circulation. Such a patient should not be considered to be suffering from epilepsy.

Toxic or Bacterial Shock

Toxic or bacterial shock does not usually develop until 2 to 5 days after injury. It may appear during the course of peritonitis following penetrating wounds of the abdomen or perforation of the appendix, as the result of infection of crush wounds or of pleural cavity wounds, and from the rupture of a gastric or intestinal ulcer. Toxic shock results from the vasodilatation of small vessels in the mesentery, internal organs and muscles, or after toxins or bacteria enter the bloodstream. Since this type of shock is a late development, the first-aid aspects of its management are mostly concerned with its prevention.

Shock of Cardiorespiratory Origin

Shock of cardiorespiratory origin is caused by respiratory obstruction, pneumothorax (an accumulation of air or gas in the pleural cavity), tension pneumothorax (sucking wound in which air enters the pleural space during inhalation and cannot escape), flail chest (chest with multiple rib fractures), hemothorax, cardiac tamponade (compression of the heart due to fluid or blood in the pericardium), injury to heart muscle, coronary thrombosis, and other disorders of the heart or lungs. All these conditions produce shock through deprivation of oxygen with resulting circulatory collapse. The symptoms of the cardiorespiratory lesion plus the symptoms listed under "Oligemic Shock" will be present in varying degrees. A large dilatation of the stomach may be a cause of shock by producing respiratory embarrassment.

It is of great importance that cardiorespiratory causes of shock, such as tension pneumothorax, not be overlooked when treating shock casualties and that prompt treatment measures be taken. Cardiorespiratory shock is treated by restoring cardiac and respiratory function. Patency of airway is an absolute requirement and may have to be obtained by resorting to an emergency tracheostomy (see "Maxillofacial and Neck Injuries"). In crush or flail chest, the chest wall must be fixed and while this is being done intermittent positive pressure oxygen must be given. The most basic way of providing this is by mouth-to-mouth breathing. If cardiac tamponade is the problem, the blood must be aspirated from the pericardium by a physician. Therefore, evacuation to facilities where professional help is available becomes urgent. In addition, the measures for the treatment of oligemic shock are indicated.

RELIEF OF PAIN

A long-accepted, *but false*, generalization is that all extensive injuries are associated with severe pain and that the more extensive the injury, the worse the pain. In reality, severe and even fatal injuries may be considerably less painful than a mashed fingertip which can cause excruciating agony. Another generalization is that, given the same causative factors, everyone experiences the same amount of pain. This, too, is incorrect. Some feel pain far more severely than others. In addition, those who would not be in much pain from a wound when rested, relaxed, and confident, might experience severe pain with the same wound if exhausted, tense, and apprehensive. Persons in shock tend to have less pain. However, pain unless relieved may cause or increase shock.

Relief of pain can often be accomplished without resorting to drug therapy. The wounded man should be reassured and brought to realize that those caring for him are taking the best possible measures, and that his injuries are understood. He should also be told of plans to obtain additional help or plans for his evacuation. These things must be related with the confidence and authority that comes only from knowing one's job well.

Pain can often be relieved by furnishing adequate support for an injury. Fractures of bones in which soft-tissue swelling occurs rapidly are extremely painful when left unsupported. Adequate immobilization of fractures not only relieves pain but prevents further soft-tissue injury and shock. Needless suffering can often be eliminated by unlacing or slitting a shoe or by loosening tight, constricting clothing in the region of an injury. Sometimes the simple adjustment of a bandage or splint will be of much benefit, especially when accompanied by a few encouraging words.

When the above measures are not sufficient, drugs must be used. The determination of which drug is to be used must depend upon the type and severity of the pain, the presence or absence of contraindications, and the availability of the drugs.

For mild pain, all that may be required is one or two aspirin or APC (aspirin-phenacetin-caffeine) tablets. These medications are particularly effective for dull, gnawing, and aching pains, especially of muscles, bones, and joints.

A-C. MANAGEMENT OF REGIONAL WOUNDS AND INJURIES

GENERAL CONSIDERATIONS

The words "wound" and "injury" have different meanings. A *wound* is a break in the continuity of body tissues involving an opening in the skin. An *injury* is a disruption in the continuity of body tissues not necessarily involving the skin. We speak, therefore, of internal injuries and external wounds. However, when the differentiation becomes awkward or obscure, the word "injury" is generally employed as in "injured extremity" even though a compound fracture may be involved. To generalize: A wound may be an injury but not all injuries are wounds.

A wound may be clean (aseptic), infected (septic), or poisoned. A clean or aseptic wound is one to which no bacteria have gained access; the best example is the wound made by the surgeon's knife. An infected or septic wound is one into which pus-producing organisms have been introduced, such as the agents which cause tetanus (lockjaw) or gas gangrene. A poisoned wound is one into which some nonliving poison, as distinguished from bacteria and viruses, has been introduced by the agent causing the wound, such as the poison delivered by insects, snakes, and, in some parts of the world, by arrows.

The general nature of wounds and injuries may be superficial or deep, slight, moderate, or severe. These may be divided into several broad groups as follows (fig. A-10):

FIGURE A-10.—Kinds of wounds. From left to right: contused, incised, punctured, lacerated.

Incised.—This type of wound is made by a sharp instrument and the edges are smooth.

Lacerated.—This type of wound results from tearing of skin and underlying tissues by blunt instruments, shell fragments, machinery, falling, etc., and has jagged edges that do not retract much. It usually consists of masses of torn tissues often with ground-in dirt or other foreign objects.

Contused.—This type is produced by blunt blows and the division of deep tissues and/or internal organs may be accompanied by more or less crushing or bruising without significant tearing of the skin.

Abrasive.—Wounds of the skin resulting from scraping or friction.

Puncture.—This type of wound is usually narrow and may be deep with a small point of entry as in stabs, bullet wounds, or snakebites. However, it may be large when caused by high-velocity, large-sized flying objects.

Crush.—This type of injury includes contusions, superficial or deep, which are caused by blasts, concussion, or other physical force transmitted to subcutaneous tissues, bones, or internal organs and usually without disruption of the skin (if the skin is involved, the surface wound is generally not of prime consideration).

In recording and diagnosis of war wounds, there are various other groupings that may be referred to. These terms are usually applicable to injuries by missiles.

Nonpenetrating.—In this type of injury the skin is not disrupted. This category includes contusions caused by blast, concussion, or other physical force causing damage to subcutaneous tissues, bones, or internal organs. These injuries may be superficial or deep.

Penetrating.—Any wound disrupting the skin with entrance of a missile or wounding agent into the subcutaneous tissues and/or internal organs without a wound of exit. Puncture wounds are included in this group, although the wounding agent may or may not have been withdrawn.

Perforating.—Any wound disrupting the skin with entrance of missile or wounding agent into the subcutaneous tissues and/or internal organs and leaving a wound of exit.

Mutilating.—This is the type of wound that causes disfiguration or the loss of some part of the anatomy as lacerations, amputations, avulsions, evisceration, extensive tissue loss, and deep burns.

Healing Processes

As the result of wounding, the skin and underlying tissues are divided; blood vessels and myriads of capillaries are also divided, and there is more or less bleeding from the cut surfaces of the tissues with a clot forming between the cut surfaces. Young connective-tissue cells and capillary buds grow into this clot from the edges of the wound, replacing the blood elements. These young connective-tissue cells and the young capillaries form what is known as granulation tissue or proud flesh. Later, the young connective-tissue cells and capillary buds develop into mature connective tissue, and the epithelium of the skin grows over it from the edges of the wound. When the cut surfaces are so close together that there is very little granulation tissue required to heal the wound, healing is said to be by *first intention.*

When the wound is gaping and considerable granulation tissue is required, healing is said to be by *second intention.* Connective tissue filling in a gaping wound forms the so-called scar.

Wound Infections

Wounds, and especially battle wounds, are potentially infected, characterized as they are by devitalized tissue, extravasated blood (blood which has passed out of the blood vessels), foreign bodies such as missile fragments, bits of clothing, dirt, dust, and a variety of bacteria. These factors are interacting. The devitalized tissue proteins and extravasated blood provide a nutritional medium for the support of bacterial growth and thus are conducive to the development of wound infection. Edema forms soon after wounding and produces tension beneath the deep fascia, further facilitating development of infection by cutting off the local circulation and depriving the tissues of blood.

Bacteria causing infection.—There are two types of bacteria commonly causing infection in wounds: *aerobic* and *anaerobic.* The former are bacteria that live and multiply in the presence of air or free oxygen, while the latter are bacteria that live and multiply only in the absence of air or free oxygen.

Principal aerobic bacteria which cause infection, inflammation, and septicemia (blood poisoning) are *streptococci*, *staphylococci*, and *Pseudomonas aeruginosa* (*Bacillus pyocyaneus*), frequently called the bacillus of green or blue pus. The staphylococci and the streptococci may be introduced at the time of wounding, but they are more commonly added later at the time of first-aid treatment when nonsterile instruments and dressings are employed, or after the casualty reaches the hospital. (It is unfortunately true that hospitals can be reservoirs of infection when crowded with casualties.)

Principal anaerobic bacteria occurring in war wounds are *Clostridium welchii*, commonly termed the "gas bacillus" and causing gas gangrene; *Clostridium sporogenes; Clostridium oedematiens; Clostridium histolyticum;* and *Clostridium tetani.* These bacteria commonly inhabit the intestinal tracts of man and other animals and are often found in soil which has been fertilized with manure. *Clostridium tetani*, or tetanus bacillus, is common in the feces of horses and cattle, and is often associated with *Clostridium welchii* in wounds. It produces a toxin which is one of the most powerful known, said to be 20 times as poisonous as cobra venom.

Inasmuch as disease-producing bacteria are present everywhere, any wound is likely to become infected with them. Contused and lacerated wounds are particularly apt to become infected with aerobic or pus-forming bacteria owing to the lowered vitality of the tissues. In badly lacerated wounds, particularly of the extremities or the buttocks, and in puncture wounds where the wound of entrance is small and is closed off by contraction of the surface tissue, a condition is created which affords a favorable environment for the development of anaerobic bacteria such as those causing tetanus or gas gangrene.

NOTE

If signs of gas gangrene are noted (edema, crepitation, slight-to-profuse watery-brown exudate with a putrid, foul odor), the patient should be evacuated to an installation where a hyperbaric (pressure) chamber is available. By subjecting the patient to a set number of hours in the chamber where a climate incompatible with the anaerobic character of the micro-organism can be created, the disease can be cured.

Causative factors in development of infection.—When infection develops in a wound, one or more of the following factors may be responsible:

1. Dust, dirt, and contaminated bits of clothing and missile fragments in the wound.
2. First aid performed under nonsterile conditions; contaminated hands, respiratory droplets, or nonsterile dressings may be contaminating agents.
3. Casts improperly applied causing abrasions and thereby introducing surface contamination from the skin.
4. Excessively tight packing of the wound, or use of tight circular bandages or unsplit casts which constrict or cut off circulation.
5. Inadequate immobilization of the part, causing further trauma during evacuation, creating devitalized tissue, and introducing surface contamination.
6. Frequent inspection of the wound or dressing under nonsterile conditions.
7. Fecal contamination of the wound: This can be particularly troublesome in wounds of buttocks and intra-abdominal areas, especially with perforated or ruptured intestines.

Most of these factors involve initial care—at the time of wounding or within a limited time thereafter.

The diver who may have the responsibility of wound management, prior to the time the services of a medical officer can be obtained, may find other factors to be responsible for infection:

1. Retention of foreign bodies in the wound.
2. Inadequate arrest of blood flow with subsequent formation of a focalized blood clot resembling a tumor.
3. Closure of a wound under tension, over dead (hollow) spaces, or in a body area in which blood supply is inadequate.
4. Failure to provide adequate drainage of old blood, exudate, and pus.
5. Frequent examination of wound and wound dressing under nonsterile conditions and introduction of secondary infection through drainage tubes, respiratory droplets, or materials.

Wound Prophylaxis

Prevention of infection should be uppermost in the mind of an individual administering first aid. It is recognized that the need to save a life must take precedence over aseptic procedures, but it should be second nature to guard the wound from contamination.

In treating a fresh wound, the following steps will discourage wound contamination (fig. A–11):

1. Scrub hands and put on any clean clothing available and tie a fresh, clean handkerchief or gauze bandage over head and another over mouth and nose.
2. Wash hands again, as thoroughly as the situation permits, preferably by scrubbing the hands and forearms with soap and hot water. Follow by application of 70 percent alcohol.
3. Place a piece of sterile gauze over the immediate wound or into a gaping wound to protect it while cleaning the surrounding area.
4. If there is much hair about the wound, remove it by cutting or shaving (with a sterile instrument) for a distance of several inches from the wound edges.
5. If there is much grease around the wound, remove it with turpentine or gasoline solvent without getting either material into the wound.
6. Clean the area around the wound, working from the wound outward so as to prevent introduction of infective material into the wound from surrounding area. Use chlorinated water or water which has been boiled 15 minutes and cooled, soap and sterile sponge or gauze, clean for a space of several inches about the wound. Remove soap with sterile gauze saturated with 70 percent alcohol. Apply tincture of Merthiolate or other antiseptics such as benzalkonium chloride solution to all parts of the skin for a

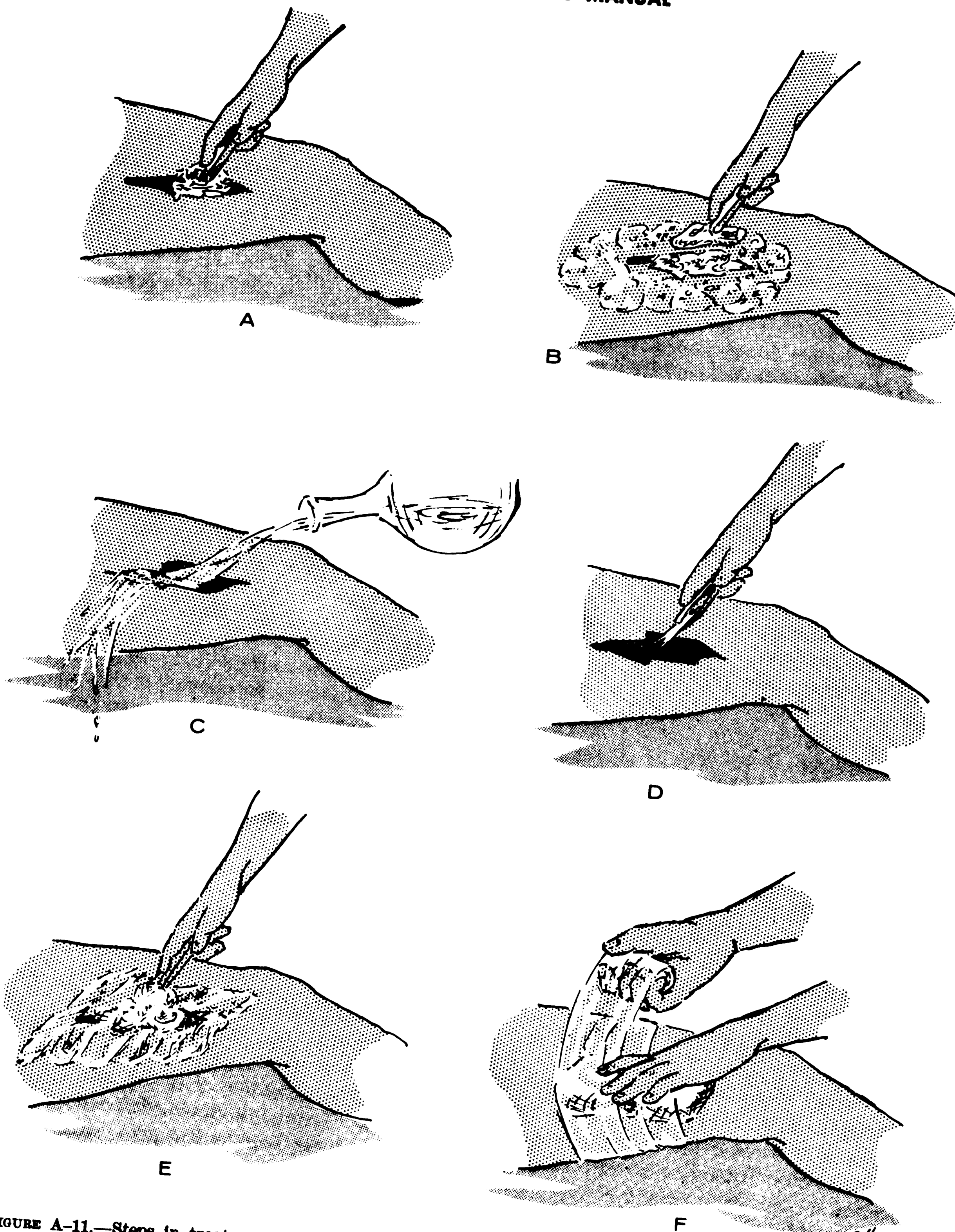


FIGURE A–11.—Steps in treatment of lacerated wound. A, place gauze lightly over wound to protect it during cleansing process; B, with soap and water, clean skin around wound; C, remove protective gauze and irrigate wound with sterile water to flush out dirt and blood clots; D, remove with sterile forceps any splinters or loose debris in the wound; E, pack wound with vaseline gauze next to raw wound surface, and then add fluffed gauze; F, apply pressure dressing and bandage.

distance of 2 to 3 inches about the wound, but allow none to get into the wound.

CAUTION

Antiseptics are of no value in the prevention of wound infection. Never introduce ether or soap, among other agents, into a wound. Their chemical effects merely cause further injury to tissues already in jeopardy.

7. Remove the piece of gauze placed over the wound to protect it and flush the wound thoroughly with sterile physiologic solution of sodium chloride (normal saline solution). If this is not available, water that has been made potable by chlorination or by boiling should be used.

8. Remove all visible foreign bodies such as glass, missile fragments, and splinters, with *sterile instruments.* Resist "probing" in the wound for out-of-sight material. More harm than good can come of this procedure, as it may disturb blood clots and precipitate hemorrhage, increase trauma to tissues, and introduce infection-causing bacteria into the deep layers.

9. Flush wound again with physiologic saline solution or purified water.

10. Place a layer of petrolatum-impregnated gauze next to the wound surface, fluff out fine-mesh, sterile gauze, and lightly pack the wound.

11. Place sterile dressing pad over wound and fix in position with a bandage applied under light pressure (unless, of course, bleeding is a problem and then active pressure with the hand over the bandage must be used to stop the hemorrhage). (See "Wound Dressings," below.)

Treatment of abrasive wounds.—Abrasions in which dirt and cinders are ground into the skin can be disfiguring if healing is permitted to take place without their removal. If days are to elapse before a physician can attend to such removal, steps should be taken to free the skin of particles, especially if the skin of the face, forehead, and neck is involved. Once healing has taken place, a tattooing effect is evident which only excision of the skin with skin graft can remove.

In general, the first five steps setting forth aseptic procedures under "Wound Prophylaxis," above, should be followed. Irrigation should then be done, which will remove most of the foreign matter, but more drastic action may be necessary for other more deeply embedded material. The area should be gently scrubbed with soap, water, and a sponge or soft brush. This will free most of the embedded debris.

If the abrasion is in an area free from pressure, no dressing is required. In other areas a protective layer of petrolatum gauze should be applied and covered with a plain dressing.

Prophylaxis for tetanus

As mentioned earlier in the text, *Clostridium tetani* is an anaerobic bacterium commonly inhabiting the intestinal tracts of man and animals. Tetanus, the symptoms of which are produced by its toxin, carries a mortality rate in excess of 50 percent. Any wound, regardless of how inflicted, must be viewed as an incubator wherein cultures of the bacterium will flourish. Fortunately, means are available to prevent this from happening.

The incubation period is usually from 6 to 12 days, but may be as short as 4 days. This is sufficiently long, however, to prevent development if proper prophylaxis is achieved within a day or two after injury.

If basic immunity has been achieved previously with tetanus toxoid, then the process is simple, for only a booster injection of the tetanus toxoid is necessary.

If the basic toxoid immunization has not been accomplished previously, the services of a medical officer must be obtained relative to giving tetanus antitoxin. Since the administration of antitoxin entails all the dangers connected with the use of any animal serum, it should never be administered without appropriate tests for serum sensitivity under the immediate supervision of a physician. If the casualty must be cared for, for more than a week without professional attendance, then consultation with a physician should be arranged via radio or shortwave.

Antibiotic therapy

Blind reliance on antibiotics to control wound infection is ill advised. Antibiotics must never be regarded as a substitute for aseptic techniques or competent surgical procedures. To illustrate: Unless adequate surgery is performed to eliminate the conditions in which *Clostridia* propagate, no antibiotic or combination of antibiotics will prevent gas gangrene in deep, irregular wounds which have been contaminated with bacilli causing this lethal infection. Antibiotics, however, do play a vital role in limiting and controlling infection.

The regimen of antibiotic therapy is not easily outlined—there are so many variables. Specific orders or directions should always be sought via radio dispatch or other available means for each patient treated. *Indiscriminate, unnecessary,* and *possibly harmful administration* of these potent agents by personnel not thoroughly trained in medicine is an ever-present danger.

Reactions from these drugs range from pruritis (itching), urticaria (hives), and gastrointestinal disturbances through acute kidney failure and convulsions followed by respiratory and heart failure.

Wound Dressings

Dressings should be differentiated from bandages in that a bandage represents the outside portion of the dressing and can be applied to contusions, among other injuries, without an actual dressing underneath it. Bandages need to be sterile only on rare occasions, whereas on all occasions when a dressing is applied to an open wound the dressing must be sterile or as nearly so as possible.

Dressings prevent introduction of bacteria and provide protection against further injury to the wound. A dressing may be—

Aseptic.—This kind is sterile; that is, it has no bacteria in it.

Antiseptic.—In addition to being sterile, an antiseptic dressing contains some substance for killing bacteria.

Wet.—A wet dressing may or may not be antiseptic. A wet antiseptic dressing generally is used on wounds which are infected.

Dry sterile.—As the names implies, this kind is free from moisture and bacteria. It is used either to cover wounds which are free from infection, or ones which are already infected and, and in this event, to prevent additional contamination.

Vaseline gauze.—This is a sterile dressing which has vaseline impregnated in the gauze to prevent its sticking to an open wound.

Any piece of cloth, however, such as gauze, linen, muslin, or a handkerchief, is suitable for use as a compress in case of emergency—provided it is as clean as possible. Dressing materials may be sterilized by boiling 10 minutes, or by heating as in an oven until lightly scorched. Once sterilized, the part of the dressing which is to come in contact with the wound must not be touched.

Dressings are applied directly over the wound and, in instances of large gaping wounds, packed snugly, but lightly, *in* the wound. Placement of gauze in the wound is called *packing.* Wound packing aids in hemorrhage control (an instance in which the gauze should be snugly packed and hand pressure applied for 5 to 10 minutes—followed by snug bandaging). This also prevents primary closure and, by keeping the wound open, maintains an aerobic climate and good wound drainage until definitive treatment can be accomplished.

A word of caution, however, regarding density of packing placed in gaping wounds, especially under circumstances where considerable time will elapse before a medical officer can attend the casualty. The wound should be *lightly* rather than *tightly* packed with gauze. Too tight a packing causes damming of pus and so widely separates the walls of the wound that later healing may be delayed. With induration (hardening of the wound due to increase of blood in the part or inflammation) the walls of the wound will become fixed and will not collapse readily. One layer of fine-mesh vaseline gauze should be used to cover the entire raw surface of the depths of the wound; the gauze should extend well above the level and beyond the skin margins of the wound defect. Then, coarse-mesh dry gauze should be fluffed with sterile forceps (folded gauze pads shaken out) and loosely placed to fill in between the vaseline gauze.

Dressings are fixed in position either by a bandage (see section, "Bandages and Bandaging," below) or by adhesive. Unless fixation is thoroughly achieved, the bandage tends to shift out of position and thereby permits contamination. Once in place, the bandage should not be removed until the casualty is in the hands of a medical officer and means are available to control hemorrhage. If bleeding does occur, the external bandage may be cautiously removed and additional gauze packed in and hand pressed for 5 to 10 minutes to reinforce the absorptive material. The wound then should be rewrapped using multiple layers of bandaging material which are applied firmly but not so tightly as to cut off the circulation.

The practice of looking at a wound to satisfy curiosity as to its progress accomplishes nothing except to further contaminate the wound and precipitate hemorrhage.

Wound Closing

The care of the wound is, of necessity, largely controlled by the tactical situation, facilities available, and length of time before proper medical care may become available. Ordinarily, the advice to a diver regarding suturing of wounds would be—*do not attempt it.*

Before discussing method of coaptation (bringing together), some of the *contraindications* to wound closing should be delineated:

1. If there is reddening and edema of the wound margins, established infection manifested by discharge of pus, persistent fever or toxemia—*do not close the wound.* If these signs are minimal, the wound should be allowed to "clean up." This process may be hastened by warm, moist (sterile water) dressings, irrigations with sterilized or saline water. These aid in liquefaction of wound necrotic materials and removal of thick exudates and dead tissue.

2. If the wound is a large gaping one of soft tissue, it is certain to contain myriads of bacteria and closure would prevent drainage of the pus that would develop. Even under the care of a surgeon, it is the rule not to close wounds of this nature until they are in proper condition. This is called delayed primary closure and is performed, preferably within 3 to 7 days after injury, upon the indication of a healthy appearance of the wound. Healthy muscle tissue which is viable (capable of living) is evident by its color, consistency, blood supply, and contractility. Muscle which is dead or dying is comparatively dark, mushy, and often malodorous. It does not contract when pinched nor does it bleed when cut. If this type of tissue is evident, make every effort to bring the patient under the care of a physician. The wound should be lightly packed with Vaseline gauze and dry sterile gauze which has been fluffed with forceps (see "Wound Dressings").

3. If the wound is deep, consider the support of the surrounding tissue and if there is not enough support to bring the deep fascia together, *do not close the surface* because dead (hollow) space will be created below. In this type of wound, which is generally gaping, muscles, tendons, and nerves most probably will be involved. Only a surgeon should attempt this type of wound closure, for reconstruction becomes necessary if it is incorrectly done.

If the wound is relatively small, shallow, freshly incurred, and is free from dirt, foreign bodies, and signs of infection, one should take steps to close it if a physician's services cannot be anticipated within a few hours.

Technique for adhesive straps

When the wound is shallow and short, edges clean and not jagged, and gaping is minimal, the skin edges may be correctly apposed and held in place by a piece of adhesive. The central portion of the adhesive should be sterilized before application by holding it over a flame (see fig. A–12).

Treatment of Infected Wounds

Despite aseptic treatment procedures in wound management, wounds still become infected. Furthermore, casualties with minor wounds may not even present themselves for treatment until infection has already set in.

Infected wounds typically show increased local pain and tenderness, redness, swelling, increased local temperature, and later, the formation of pus. A spreading infection is often characterized by inflammation of the lymph channels (red streaks leading away, in a proximal direction, from the wound), with or without pain, tenderness, and swelling of the lymph nodes draining the infected area (fig. A–13). In local infection, the involved area is usually clearly defined, such as a well-localized boil. In spreading infection, the margins are ill defined and there is obvious involvement of surrounding tissue.

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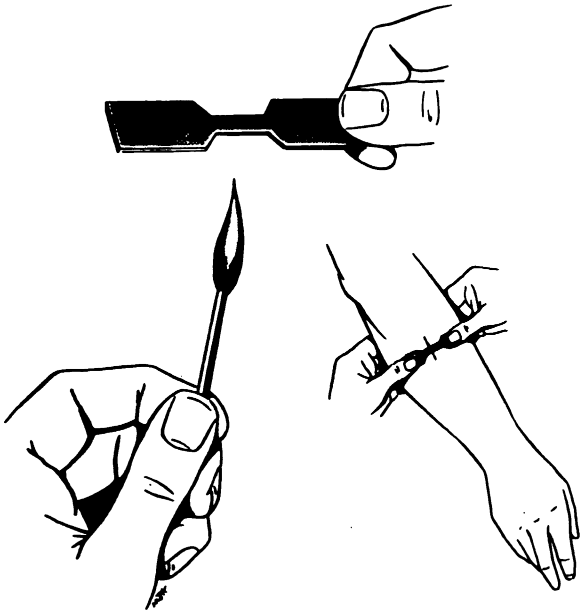


FIGURE A–12.—Butterfly adhesive strap.

The treatment of a locally infected wound is directed toward cleansing the wound, improving the circulation to the area, and controlling the invading organisms. In general, the following steps should be taken:

1. Elevate and immobilize the infected part.
2. Remove foreign bodies if easily accessible. Do not probe in the depths of the wound.

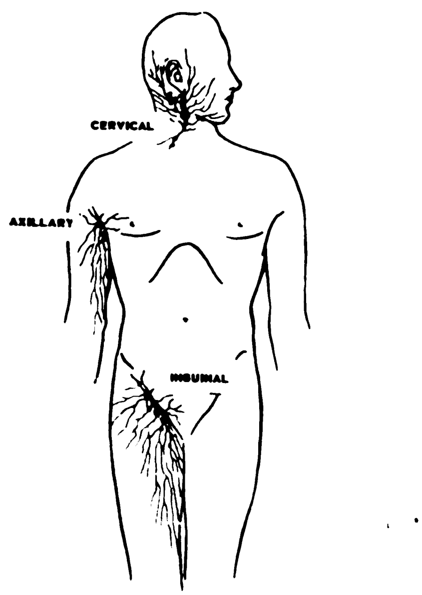


FIGURE A–13.—Location of principal lymph nodes.

3. If the wound has been closed, obtain good drainage. Insert drain of rubber dam, or wick of Vaseline gauze.
4. Apply a warm, wet, sterile dressing.

The treatment of a spreading infection with grave systemic symptoms *demands* the advice of a physician. Make every effort by two-way radio, telephone, or radio dispatch to contact a medical officer, or to transfer the casualty to a hospital facility. In the interim, the patient should be put in bed to provide maximum rest, fluid intake should be maintained at a level that permits the excretion of 1,000 to 1,500 milliliters of urine daily, and pain and restlessness should be controlled by analgesics as appropriate.

If it is suspected that the wound is infected with tetanus or gas gangrene anaerobes, the wound should be opened up so that conditions which favor their growth do not exist. The wound cavity should be irrigated gently with sterile saline solution or purified water, provision made for drainage, and the wound loosely filled with gauze.

CRANIOCEREBRAL INJURIES

Craniocerebral injuries may be classified as injuries to the scalp, skull, and brain. The role of a diver managing craniocerebral injuries is extremely important. First-aid aspects are centered upon control of hemorrhage and prevention of infection and further damage to vital structures within the skull.

Injuries of the Scalp

The scalp is the covering skin of the head which normally is covered with hair. It is rather loosely applied to the skull and is richly endowed with blood vessels, and for these reasons hemorrhage and infection are particularly troublesome. Hematomas constitute the most common of the scalp injuries and are generally caused by a blow from a blunt instrument or a fall. Cutting wounds frequently result in hemorrhage which must be controlled without pressure over the site of injury until all possibility of fracture and intracranial involvement have been ruled out.

Before any attempts at first aid are made, the ears and nose should be checked for leaking cerebrospinal fluid or blood. Leakage would indicate skull fracture. Loss of consciousness, difference in size of pupils and their reaction to light, loss of reflexes, and vomiting are all indications of brain damage. Any pressure at the site of injury would, therefore, be contraindicated.

Hematoma

The diagnosis of hematoma may be made by inspecting the scalp and finding a tender, soft, fluctuant mass. If small, it seldom needs any treatment. If massive, arrangements should be made to evacuate the casualty to professional care.

Hemorrhage

Any cut in the scalp can cause profuse, even fatal, bleeding. This is especially true of the occipital and temporal regions. If none of the signs of fracture or brain involvement is present, the bleeding can best be controlled by exerting pressure on a dressing placed directly over the bleeding point. This is much more effective than pressure over the artery proximal to the wound. However, if fracture is involved, pressure at the bleeding site is not possible. The common carotid artery controls the blood supply (on the same side of the head) to the neck, head, and some of the brain. Three fingers should be placed on this vessel with the thumb carried around to the back of the neck. Pressure should be exerted toward the thumb, never toward the windpipe. Also, pressure should always be exerted at a point lower than the Adam's apple. Major blood supply to the scalp is derived from the temporal and occipital arteries, but pressure often will not stop blood flow as well as hoped because of extensive collateral vessels. Nonetheless, it should be attempted.

In denuding or scalping injuries, the denuded area should be irrigated with sterile normal saline solution as promptly as possible and cleaned of debris, the surrounding hair clipped and shaved, and Vaseline gauze laid in place over the raw area. Professional advice should then be sought.

Injuries of the Skull and Brain

The skull is the bony framework which encases the brain. Fractures of the bone itself are not as important as some (the weight-bearing bones, for example), but are serious because of the damage that might be delivered to the brain by the force which caused the fracture. Fractures may be *depressed*, i.e., when a section of the skull is pushed inward, and this may occur with or without laceration of the overlying scalp; or *compound*, in which there is a laceration of the scalp, a fracture of the bone, and very often a laceration of the membranes surrounding the brain—even penetration of the brain itself.

Symptoms

Open brain injuries are easy to identify; closed brain injuries are not always so easy to diagnose. These injuries may be caused by blast, blunt blows, and jolts. Many of the symptoms and signs may suggest other conditions, such as intoxication, heat exhaustion, and diabetes, among others. The victim of a closed head injury generally exhibits unusual behavior patterns, such as aimless wandering, memory defects, drowsiness, apathy, mutism, stupor or, just the opposite, excitability, loquacity, and delirium.

In general, symptoms develop in proportion to the severity of the condition. Most important of all symptoms from a standpoint of both diagnosis and treatment is the *state of consciousness*, and of particular importance are *changes in the state of consciousness*.

In the conscious patient there may be headache aggravated by forward bending, coughing, or straining. There may be unusual eye movements and the pupils may be unequal in size. Also, sudden paralysis of one entire side of the body (hemiplegia) or of one leg or arm, sudden impairment of vision or blindness, and projectile (extremely forceful) vomiting may occur.

Blood-pressure changes often consist of rising systolic pressure with less rise in the diastolic (widening pulse pressure). The pulse rate frequently slows to 60 or less and respiration may slow down.

In instances where the dura mater (fibrous membrane forming the outermost covering of the brain) is penetrated, the cerebrospinal fluid may escape from the spaces around the brain and leak out. The two most common places for this fluid to reach the outside of the body are through the ears and nose. The uninitiated are sometimes astonished at the amount—sometimes a quart or more a day—which may drain through these orifices.

It is extremely important that all symptoms and data secured at the preliminary examination be carefully recorded. This is especially true when hours may elapse before the casualty can receive professional care. Treatment will be based upon a general and neurologic examination performed as soon after wounding as possible. The evaluation should cover the following points:

1. *Head examination.*—This to include description of wounds, hematomas, scalp depressions, and any escaping fluid or blood from nose, ears, or throat.

2. *Mental evaluation.*—This to cover state of consciousness, i.e., whether conscious (alert and oriented to time and place), confused (alert but disoriented and excited), semicomatose (drowsy and stuporous, response to painful stimuli but otherwise no movement), or comatose (no response to painful stimuli). The state of consciousness should be determined at least every hour or more often if the patient is severely injured.

3. *Eye examination.*—This to cover size of pupils with any inequality in size noted, and their reactions to light and accommodation (far and near vision). Movements of the eyes as they follow a test object should also be checked with special attention directed to their ability to converge for near vision and to move in unison.

4. *Motor function.*—This to include evidence of any weakness or paralysis of an extremity or of facial or eye-movement (extraocular) muscles. If weakness is progressive, times of changes and areas involved should be noted.

5. *Vital signs.*—This to include temperature, pulse, respiration, and blood pressure. These should be determined every 15 minutes until condition has stabilized.

6. *Speech characteristics.*—This to cover evidence of garbled or slurred speech, or rambling, disorganized thoughts. If the casualty becomes lucid, then loses his ability to express himself, times of changes should be noted.

7. *Sensation reactions.*—This to cover reaction to pinprick in various areas of arms, legs, face.

Treatment

Primarily, all activity is centered upon prevention of infection of, and further damage to, vital brain structures; management of the casualty so that when he is seen by a surgeon he is in the best possible physical condition; and recording data which will assist the operating surgeon in evaluating the type, area, and degree of injury.

A casualty with a craniocerebral injury should be subjected to the least possible handling, and this in the gentlest possible manner. In the lightly wounded, headache may be extreme and, if so, will be aggravated by motion; in the seriously wounded, the brain may be further damaged and even death may result from overly vigorous movements. It is well to keep in mind that essential brain cells have no healing power whatsoever like bone cells have, for example. Damaged cells are replaced by scar tissue which not only has no brain-type function, but acts as an irritating agent which can prevent normal life. In summary, the watchwords of management of head injuries are cleanliness, gentleness, and quick hospitalization.

An immediate appraisal of the casualty's general condition is of prime importance. The establishment and maintenance of a patent airway, particularly in unconscious patients, takes precedence over all maneuvers. The mouth, nose, and throat must be kept free of mucus, blood, and vomitus.

The casualty should be positioned on his side or face down with head below body level. This will promote drainage of secretions and, in the stuporous casualty, keep a relaxed tongue from blocking the airway. But, once again, a word of caution. If there is a fracture of the cervical spine, the casualty should not be so positioned (see "Spine and Spinal Cord Injury").

Any gross bleeding should be brought under control. The area around the laceration should be shaved widely, and the laceration irrigated with normal saline solutions. Knowledge of the location of arteries supplying different areas of the scalp is essential and compression of the artery should be well away from the fracture site.

In instances of compound fracture where bone and debris have been driven into the brain, and the brain perhaps exposed, irrigation should not be attempted. The shaved and cleaned area should be covered with a loose dressing and professional advice should be sought.

After all danger of vomiting has passed and bleeding has stopped, the casualty may be gently turned on his back and his head elevated slightly (about 15 degrees). This position seems to facilitate venous return and to combat edema.

The casualty should never attempt to clear his nose by blowing and should be so cautioned. Nor should any attempt be made to plug his nose or ears when blood or cerebrospinal fluid is escaping, even though the flow is copious. Simply allow drainage to continue.

Any attempts to clean immediate avenues of escaping fluid, even though obviously contaminated with dirt, are contraindicated. This is especially true of syringing which might wash organisms back through the laceration to brain tissue which is highly susceptible to infection.

Blood clots should not be dislodged, and under no circumstances should the wound itself be disturbed. *Any foreign bodies embedded in the depths or any protruding objects should be left in place.* Only obviously loose material, as a piece of contaminated cloth adhering to the surface, may be removed with safety. Great care is necessary in applying dressings to wounds of this nature lest the foreign bodies be touched and the resulting motion disturb the deep structures and cause hemorrhage or irreparable functional damage.

Injury to the brain itself does not cause shock. Unless there has been excessive bleeding or vomiting, look elsewhere for the cause if the patient is in shock. There may be hidden bleeding in the chest or abdominal cavity, or fracture displacement of a major bone, among other things.

Pain is not ordinarily a prime consideration in casualties with wounds limited to craniocerebral areas. Restlessness, mental confusion, acute excitement states, even mania and convulsions may follow brain trauma and control of these is, of course, a problem. The victim must be protected from inflicting further injury to himself.

In management of some of these casualties, physical restraints may prove necessary. The casualty should seldom be tied down, since complete lack of freedom only causes alarm and increases excitement. A restraining sheet is probably best, as this allows some motion but confines the patient to bed. Nursing care can become a serious problem in transporting those who are restless or excited.

SPINE AND SPINAL CORD INJURIES

Injuries to the spine and spinal cord are usually caused by falls, diving into shallow water, automobile and aircraft accidents, vigorous contact sports, gunshot or stab wounds, and decompression sickness.

In instances when the spinal cord itself is injured, the results are grave. All motion and all sensation below the level of the lesion are suppressed. Division of the cord above the fifth cervical vertebra is rapidly fatal unless an adequate form of artificial respiration is maintained. The reason is that the nerves which maintain diaphragmatic breathing emanate from that portion of the spinal cord located at the third and fourth cervical vertebrae.

In injuries of the spine such as fractures, dislocations, and strain on supporting structures (whiplash injuries which occur when an automobile is struck from behind and the body of the passenger is thrown forward, the head snapped backward, and then again violently forward), the outcome at times may be more favorable. Nevertheless, there is always a definite danger of cord injury until the fracture or dislocation has been reduced (corrected or restored to its normal place). Hence, the need for utmost gentleness in handling these injuries.

Symptoms

When the spinal cord itself is injured, the level of the lesion can be determined by observing the casualty closely, since the region innervated by each segment of the spinal cord has been accurately determined. The control center is the brain and the fiber tracts that compose the motor nerves pass down the spinal cord from the brain.

If the casualty cannot move any of his extremities (or does not respond to pinprick if he is unconscious), the lesion must lie in the upper cervical (neck) region. If the arms can move but the legs cannot, the lesion must lie below the lower cervical cord which innervates the upper extremities and above the lumbar cord which innervates the lower extremities. Any lesion above the sacral cord will cause retention of urine, as will a lesion of the sacral cord itself.

In fracture and fracture dislocation in which the cord itself is not involved, the injured will have immediate symptoms of pain, limited motion, and muscle spasm in the area of the injury and the area innervated by the particular segment.

Fracture and fracture dislocation of the first 10 thoracic (dorsal) vertebrae are much less frequent than those in the cervical or lumbar regions because of the relatively limited movement of this part of the spine to which the rib cage is affixed. Fractures are more common from the 10th thoracic to the 4th lumbar, with the most frequent site being the 12th thoracic and 1st lumbar. If the patient complains of acute pain in the back which may radiate down the lower extremities or around the chest and abdomen, it suggests involvement of the thoracolumbar spine.

Treatment

When a disabled person has obviously sustained a major back injury and especially if extremities show evidence of neurologic involvement, every precaution must be taken to protect the spinal cord from damage or further damage, for it is unfortunately true that 1 out of every 10 who sustain back injuries has the injury extended as a result of improper emergency care.

The first precaution should be to take time to assess the area of the spine involved (see "Symptoms" above). The casualty should be left in the position found and a coat or blanket placed over him to prevent loss of body heat—he should never be rolled over and placed in a more comfortable position and under no circumstances should he be placed in a sitting position. Once the area involved has been determined, then the correct method of moving and transporting the injured person can be decided.

In injuries of the *cervical spine*, the casualty should be transported face-up on a hard surface with a small rolled towel beneath his neck and padding placed on each side of his head and neck (sandbags are best if available) to prevent movement. Casualties with fractures of the *thoracic and lumbar spine* should be transported in the supine position also, with a folded towel or coat placed beneath the curve of the spine as shown in figure A–14. The casualty should be placed on a hard stretcher, and he should be moved all in one piece, so to speak, the point being that flexion *must be* avoided.

At the hospital or receiving station, the same care should be exercised in transferring the injured to his bed as in moving him from the scene of the accident. The bedclothes should be free of creases. All hard objects, such as wallets, keys, buckles, should be removed from the patient and all bony prominences padded (decubitus ulcers—pressure sores—have their inception early and can be very serious during the

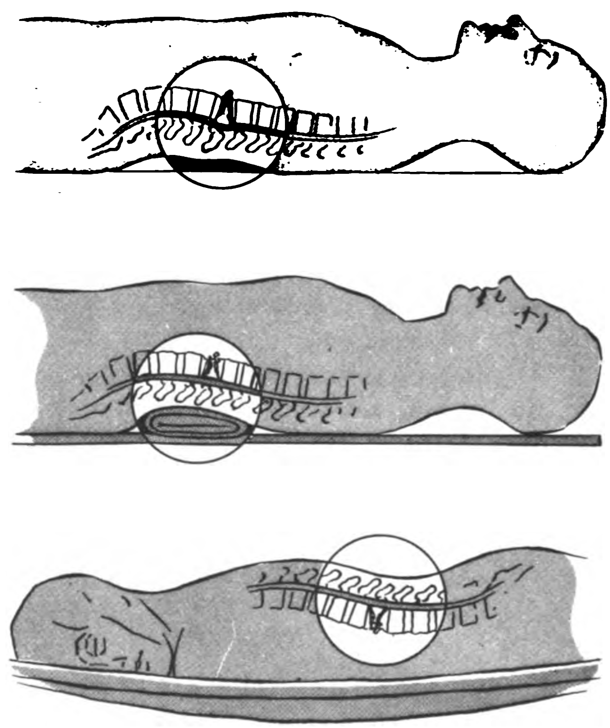


FIGURE A–14.—Proper position for transporting a casualty with a fractured spine. Top figure shows need for support at arch of back. Center figure depicts correct method: firm stretcher and back support relieving any tendency of pressure on spinal cord. Bottom figure shows lack of support by flexible litter and soft abdominal organs.

long period of immobilization which follows most serious injuries of the spine).

Shock may demand evaluation and treatment. The mouth and trachea should be kept clear of secretion, and suction should be used if necessary.

Treatment of these casualties can only be assumed by professional specialists and, if accidents involving the spine occur aboard ship or at isolated stations, plans for evacuation should be made immediately.

While awaiting transportation, the divers responsible should follow certain principles of management and be able to solve troublesome problems which are likely to arise.

As a rule, a patient with an injured spine will have considerable abdominal distention and difficulty in voiding and evacuating his bowels. These symptoms may be materially alleviated by hot applications to the abdomen, but caution must be observed to avoid burning the skin.

Open wounds should have simple soap-and-water cleansing of the skin and a sterile dressing. They should not be investigated for foreign bodies. If there is a leak of cerebrospinal fluid, the surrounding area should be kept meticulously clean, and a voluminous dressing firmly applied.

Good nutrition and fluid balance must be maintained. Toward this end, high-fluid intake and high-caloric diet with large protein component are recommended.

MAXILLOFACIAL AND NECK INJURIES

Injuries about the face, mouth, jaw, and neck are generally serious because of the danger of hemorrhage due to the rich blood supply of the area and because of the danger of obstruction to the respiratory passages.

Surface wounds, particularly closed wounds such as contusions, seldom require treatment of an emergency nature. Open wounds, however, may require prompt action, since many involve the deep structures; hemorrhage into the throat and windpipe, with resultant asphyxia, can be an immediate and real danger.

Symptoms

Both the injured and uninjured sides of the head and face should be compared to detect variance in bony landmarks. Deformities of the nose; variation in the level of the eyeballs and any eye hemorrhage; any poor alinement of upper and lower teeth; any disturbance of function of the jaw; or any contusions, swellings, or hematomas give evidence of deep damage. (Any escape of cerebrospinal fluid from nose or ears indicates brain involvement. See "Craniocerebral Injuries" for management.)

In contused or closed wounds, blood often escapes into the tissues and forms a hematoma, but rarely does this type of injury pose any immediate threat to the air passages. More important in this type of wound is the possibility of fracture. Fractures occur more frequently in the lower jaw and are generally easily detected because the casualty cannot open or close his mouth without a great deal of pain, and swallowing is difficult.

Open wounds are to be considered as serious, for the blood flow is often violent and may block the respiratory passageway in seeking an exit. Coughing, strangling, or cyanosis are signs that blood—and possibly tooth fragments or dislodged tissues and debris—are being aspirated. Blood and air foaming from a wound in the neck indicate that a wound exists in the trachea, or neighboring pharynx or larynx, with associated injury to an important blood vessel. In crush injuries, hemorrhage will be profuse from nasal or oral cavities and indicate involvement of sinuses, jaws, and respiratory passages. If the jaw is shattered, the pharyngeal passage may be blocked by a prolapsed tongue.

Treatment

As indicated above, the two conditions to be considered first in the seriously wounded are hemorrhage and maintenance of an open airway. Asphyxia must be treated immediately. The position of the casualty is especially important if he is unconscious or semicomatose. The mouth should be opened and swiftly cleared of any broken teeth, shattered bone fragments, or other foreign bodies such as dentures, and the injured patient positioned in a prone or semiprone attitude to permit gravity drainage through the mouth and to counteract a relaxed tongue.

Crushing blows to structures of the nose and face are frequently encountered in accidents involving swiftly moving objects. In this type of accident, the force producing the accident will likely have injured the brain, causing unconsciousness. Since the hemorrhage will generally be coming from inside the oral and nasal cavities, there is grave danger of the patient drowning in his own blood. Prone positioning with the neck hyperextended to maintain an open airway is probably the best solution since the hemorrhaging vessels will not, in all probability, be accessible to the rescuer. If there is evidence of concomitant injuries to the cervical spine (for which the prone position is contraindicated), the best solution is to provide an airway. Emergency tracheostomy can be lifesaving in such instances (see "Emergency Tracheostomy" below for procedure).

In fracture or crushing injuries of the jaw, the swollen or prolapsed tongue may obstruct the airway. By pressing downward against each side of the lower jaw bone or by inserting a gauze-covered stick between upper and lower teeth, the mouth may be opened and the tongue pulled forward, freeing the pharynx. This maneuver is easier if the fingers are covered with gauze or a clean handkerchief before grasping the tongue (see fig. A–15).

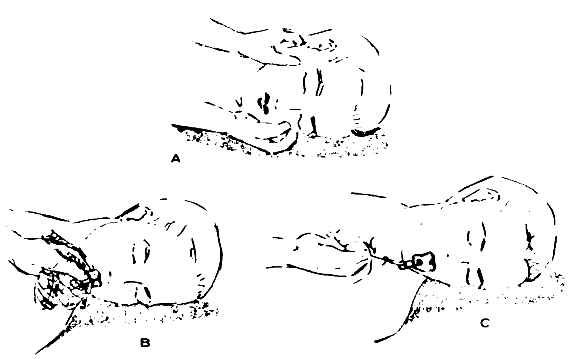


FIGURE A–15.—Methods of freeing the pharynx when the jaw is shattered. A, the jaw is held forward by pressing downward against the side of the lower jaw bone; B, the tongue is grasped with gauze-covered fingers and pulled forward, freeing the pharynx; C, the tongue is pierced with a safety pin to aid in holding it in the seriously injured, unconscious patient who must be transported some distance.

The casualty with a deep wound of the neck accompanied by laceration of the trachea is in critical danger of drowning in his own blood. This combination of injuries is manifested by air foaming through the blood flowing from the wound. If the neck is extended, the wound becomes enlarged and this may permit insertion of the fingers which can press against the bleeding site. Since the injured part of the pharynx may be blocking normal air exchange, the inhalation and exhalation of air through the wound should not be interfered with. Once hemorrhage is controlled, an effort should be made to establish an airway at the point of laceration. A fountain-pen case, plastic or rubber tubing, or any firm cylindrical object of suitable size with a hole in the center may serve in an emergency. These measures are makeshift, but they may prevent the wounded person from suffocating and thus borrow enough time to bring him to professional medical care.

When large vessels of the neck (carotid and jugular) are cut, loss of blood is rapid and difficult to control. Pressure should be applied firmly against the carotid between the wound and the heart and against the deep muscles backed up by the vertebrae. *But*, the pressure should not be so forceful as to depress the airway. If bleeding is controlled, the casualty must receive blood transfusions immediately if he is to survive the shock which inevitably follows great blood loss.

Control of surface bleeding is by direct attack upon the bleeding point. The vessel is controlled by firm digital pressure on a gauze pad. If pressure at the site does not stop the bleeding, the artery supplying the area should be sought and compressed. The blood supply to and around the nose and upper lip is derived chiefly from the nasal and infraorbital arteries, and around the lower lip from the facial artery. (See plate 1 for these and other pressure points.)

Contused or closed wounds require little treatment other than an icepack over the injury. The pack should not be left on longer than 2 to 4 hours since the tissues may be devitalized because of the cold. Following the cold treatment, heat should be applied to cause dilation of the vessels constricted by the cold. This promotes healing. Contused wounds may produce hematomas and if gentle pressure is applied to the icepack some bleeding into the tissues can be averted.

Abrasions are not as serious as certain other wounds from the standpoint of being life endangering, but dirt, cinders, and the like ground into the skin can be very disfiguring especially if about the face. If the casualty will not be seen by a physician within 24 hours, steps should be taken to cleanse the area, for healing will entrap the dirt, creating an unsightly tattoo effect. (See "Management of Wounds" in this appendix for methods of cleansing.)

Treatment of serious maxillofacial injuries can be assumed only by specialists and if accidents occur at isolated stations or aboard ship, every effort must be made to bring the injured to immediate professional care. Management of these casualties while awaiting transportation involves many of the usual problems such as shock and fluid replacement. Infection can be particularly troublesome because of the pathogens (any disease-producing micro-organism or material) in the oral and nasal cavities. See pertinent sections of this appendix for procedures and regimens. Nutrition and fluid balance are also of concern and will be so from time of injury throughout fixation and repair. In any event, the diet should be primarily liquid and maintained at a high-caloric, high-protein content.

Emergency Tracheostomy

Tracheostomy (opening the trachea and placing a breathing tube through the opening down the trachea) is a lifesaving procedure which is limited to employment in those instances where an adequate airway *must* be provided to preserve life. It is undertaken for relief of menacing asphyxia caused by obstructions of the airway such as fracture of the trachea, spasm of the glottis due to a foreign body in the larynx, edema of the larynx, and prolapsed or swollen tongue, among others.

The trachea, or windpipe, is a tube composed of cartilage and membrane, extending from the Adam's apple to the suprasternal notch, with rings of the cartilage forming the framework. An anatomic representation of the blood vessels and structures in the front of the neck is likely to destroy the confidence of the nonprofessional being trained to perform emergency tracheostomy. Essentially, only these facts are important:

The thyroid cartilage is the largest cartilage in the larynx and is a landmark. It consists of two flat plates which are fused with each other at an acute angle in the middle line of the neck and form a subcutaneous projection called the Adam's apple. This prominence is larger in the male than in the female, but is easily identifiable in both sexes. The cricoid cartilage immediately below is smaller and thicker and stronger than the thyroid and forms the lower and posterior parts of the wall of the larynx. Incision through skin and fascia can be carried down the midline from the lower border of the thyroid to just above the suprasternal notch without endangering any important structures—all the structures that must not be cut are at the sides.

The casualty should be placed with a pillow, rolled blanket, or sandbag under the shoulders so that his neck is arched and his head is well back (see fig. A–16). The skin is then pulled tightly over the trachea to make it tense. A mid-

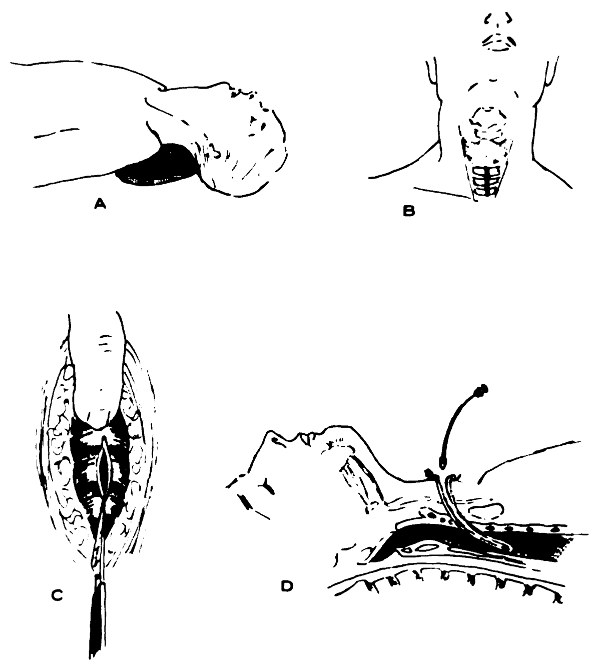


FIGURE A–16.—Technique of tracheostomy. A, position of the patient with neck hyperextended; B, location of incision; C, incising trachea; D, tracheotomy tube in place.

line incision which is *shallow* and *divides the skin and fascia only* is made from the lower border of the thyroid cartilage to just short of the suprasternal notch (see fig. A–16*B*). (Care must be taken to stop short of the bone lest the great vessels, which rise high in the suprasternal notch when the neck is extended, be incised.)

The cricoid cartilage is located and the deeper dissection is continued below it. After the strap of ribbon muscles is separated in the midline of the neck by blunt dissection, the trachea is exposed. If the isthmus of the thyroid (a narrow strip of thyroid tissue connecting the lateral lobes of the thyroid gland) is encountered and is obstructive, it can be gently retracted upward. The trachea appears to be corrugated; if it is not visible it can be easily palpated (felt) with the forefinger. The incision into it should split the midline and be sufficient to permit insertion of a tube when the walls are retracted (see fig. A–16*C* and *D*). Splitting of the second and third rings *below* the cricoid, never next to the cricoid, should produce enough of a separation but if not, the fourth tracheal rings may also have to be divided. The incision may be held open with any number of tools (see discussion below).

NOTE

A long-taught emergency approach for a tracheostomy was a transverse incision between the thyroid and cricoid cartilages. While this location approached the larynx in its most accessible, superficial, and bloodless area, it was very close to the vocal cords and the stricture of the larynx which followed has caused this approach to be virtually abandoned.

In an emergency tracheostomy, rarely will the special instruments as scalpel and tracheotomy tube be available. A sharp pocket knife or razor blade may be used in lieu of the scalpel and large-bore rubber or plastic tubing in place of the silver tube. When tubing is not available, the tracheal incision may be held open with improvised retractors made either of clean wire, or instruments such as forceps or hemostats. The wire should be about the length of a hairpin—indeed a hairpin may be used—the free ends should be twisted together and the curved end bent into an acute angle and then inserted into the lateral edges of the tracheal wound. These retractors are then secured by tying a string to the twisted ends of the hairpin and then tying this behind the casualty's neck. The casualty can then be transported to a station or hospital where, under sterile conditions and without haste, corrective work can be done, a regular tracheotomy tube inserted, and the skin incision closed loosely with sutures.

If suction is not available to remove secretions from the trachea, the head should be lowered as soon as the trachea has been opened.

NOTE

If a foreign body is suspected of causing the obstruction and the obstruction is only partial, i.e., manifested by spontaneous but inadequate and noisy breathing, tracheostomy is *not* indicated. The supralaryngeal portion of the airway should be explored with the finger to effect removal of the object and, if this is not effective, then the jaw should be elevated and the neck hyperextended. This maneuver may free the airway enough to provide adequate ventilation until the patient can be brought to professional help. In children, picking them up by the ankles and delivering several firm slaps on the back may dislodge the obstruction.

EYE INJURIES

Unless the injury to the eye is plainly a minor one, the best advice would be to refrain from interference. Ocular injuries are more serious than similar injuries to other tissues because of the ever-present danger of visual loss. A minor wound improperly managed can progress to a serious one, and a penetrating wound may result in blindness.

The most frequently occurring injuries result from foreign bodies lodging or embedding in ocular tissues. But, under battle or emergency conditions, injuries may range from trauma to the eyelids, hemorrhage into the chambers of the eye, laceration of the globe, to enucleation (removal) of the entire globe.

Without special instruments or knowledge of specialized techniques, interference of the untrained in eye injuries which are not clearly minor may lead to disaster. First-aid care is, therefore, conservative and directed toward bringing the casualty into the hands of a specialist at the earliest time and in the best possible physical condition.

Symptoms

Before an examination to determine the extent of the injury, all foreign matter such as dirt and sand must be removed with copious irrigations of plain sterile water, physiologic salt solution, or any potable water if obtaining either of the preceding is going to be time consuming. For this procedure the lids are everted (see fig. A–17 for procedure). Eversion must be accomplished with no pressure at all on the globe, for the slightest pressure on a lacerated or perforated globe may cause extrusion of part or all of the vital contents.

A penetrating wound should always be suspected until it has been ruled out. Indications of a penetrating wound are (1) visible defects of the cornea or sclera, (2) visible intraocular bodies, and (3) protrusion of transparent material (vitreous humor, aqueous humor, or lens), or of pigmented material (iris, ciliary body).

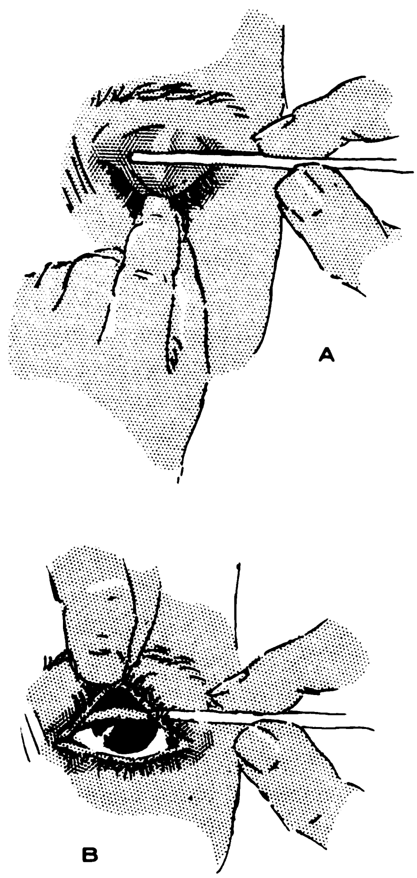


FIGURE A–17.—Technique of everting eyelid. A, depress the upper lid with an applicator stick and grasp lash between thumb and index finger; B, evert the lid by lifting it up over the applicator stick.

Treatment

The most common eye injuries are caused by flying particles which lodge in the conjunctiva or cornea. Only superficial foreign bodies should be removed by the diver. After the lid is everted, gentle irrigation may flush the free particles out. (When only one eye is affected, spasm of the eyelid (blepharospasm) may be troublesome. It may be overcome by holding both lids open.) A cotton-tipped applicator which has been *moistened* with sterile water may be used to remove the more stubborn particles which adhere to but are not embedded in the conjunctiva or mucous linings of the lids. Great care must be exercised in the use of the cotton applicator because of the extensive damage which can be rendered to the delicate epithelium.

Ointments should not be used in the eye. If the wound is not penetrating or acutely painful, the eye should not be bandaged shut. Bandages encourage incubation of micro-organisms and, if the eye is closed 48 hours, the conjunctival sac will fill with pus. Therefore, a protecting gauze flap attached by a string of adhesive tape on the forehead and left hanging free is preferred.

If the foreign particles have penetrated and are embedded in the cornea, sclera, or deeper structures, the casualty should be brought immediately to the care of a specialist. These particles most frequently consist of shell or other metal fragments, glass, wood, dirt, sand, or stone, which are traveling with considerable velocity at the time they hit the eye. To prevent further damage, the injured person should be evacuated, recumbent, on a litter. His head should be fixed in position by rolls of towels or sandbags, and both eyes should be gently bandaged. He should be instructed on the importance of not squeezing his lids together, as the pressure on the eyeball may result in extrusion or loss of contents of the globe. Also, he should be told not to strain, lie on his stomach, or even to perform such ordinary tasks as removing his own clothing.

Local medications should not be used in or about the eye and no drugs which may produce vomiting should be administered for pain.

Contusions (bruises) of the eyeball and eyelids should always be carefully examined. Superficial soft-tissue injury itself is rarely significant. If there is no disturbance of vision and only subcutaneous and subconjunctival hemorrhage, the patient need not be evacuated. The application of an icepack or cold-water compress within the first few hours may limit interstitial hemorrhage.

If there is any evidence of internal hemorrhage, such as disturbance of vision, any damage to the iris, lens, or retina, specialist care is indicated and the casualty should be evacuated. Any injury severe enough to produce intraocular hemorrhage may cause secondary hemorrhage and detachment of the retina. Such patients should have absolute bedrest for 1 week with both eyes bandaged in order to prevent further bleeding.

If the injury has torn or split eyelids, moistening of the cornea becomes a problem. The cornea should never be allowed to become dry; coarse gauze dressing should never be applied over the unprotected area. Careful bandaging will be necessary to be sure that the mucous membrane covers the cornea. After the lids are closed, they should be dressed with petrolatum gauze.

Chemical burns

As a rule, acid burns are instantaneous. The extent of the burn depends upon the concentration of the acid and the duration of exposure to the tissue before dilution and removal. Acid burns are not progressive and heal more rapidly, in general, than do alkali burns. Immediate treatment of all such burns is copious washing of the eye with water (fig. A–18). This may be either canteen or tap water, for speed is a must. Of course, if a 5-percent sodium bicarbonate solution is available it should be used for washing the conjunctival sac. Considerable pain is usually present. The eye should be gently irrigated for 15 to 30 minutes depending upon the quantity of the chemical; special attention must be paid to flushing under both eyelids.

Immediate treatment for alkali burns (lye, carbon dioxide absorbents, and many cleaning agents) is also copious irrigation. Alkali has a tendency to "burrow," and every bit of alkali must be removed. The face should be thoroughly

FIGURE A–18.—Technique of irrigating eye.

cleaned and the eyes irrigated for from 30 to 45 minutes with a weak solution of vinegar (3 percent acetic acid in water). The lids should be moved from time to time and the casualty should roll his eyes to be sure the entire surface of the eyes and lids are washed. Alkali burns are progressive and the casualty should be brought to professional care as soon as possible.

Thermal burns

Because of the blink reflex, thermal burns of the eye are generally limited to the lids. Minor burns are best treated by first closing the lids and then applying a petrolatum gauze dressing. The dressing should be left in place for 48 to 72 hours.

If the burns are severe, in all likelihood there will also be severe burns about the face and body. Shock may complicate the picture and demand the initial treatment. After starting the treatment, therefore, the conjunctiva and globe as well as the lids should be carefully inspected to determine the full extent of the injury. Any foreign matter not embedded should be washed out with gentle irrigation. The burned surface of the closed lids should be covered with two or three layers of sterile petrolatum gauze and a moderate pressure dressing applied.

When the conjunctiva and globe are severely burned, as by molten metals and metallic sparks and cinders, professional care should be sought immediately. Irrigation may flush out free particles. Since dressings tend to increase the possibility of infection and prevent draining of secretions, the eye should be left open.

Flash burns

Exposure to ultraviolet rays may burn the cornea as can happen to those looking at carbon arcs and welders' arcs without benefit of protective glasses. Burns of this type may result from prolonged exposure to the dazzling light of snowfields and open water. The first symptoms are scratchiness and tearing, followed by photophobia (light sensitivity) and blepharospasm (spasm tending to close the eyelids). Ice compresses and an analgesic may be prescribed to promote healing and comfort.

EAR INJURIES

Injuries to the external ear (auricle) generally take the form of contusions, abrasions, and lacerations and are usually caused by glancing or direct blows. Injuries to the middle and inner ear are frequently associated with blast, fractures of the base of the skull, or barotrauma, and impairment of hearing is a strong possibility.

Symptoms

Injuries of the auricle require treatment to prevent infection. Neglected wounds may become swollen, reddened, and edematous with a resultant "cauliflower" deformity. Blast injuries, in air or under water, often cause rupture of the tympanic membrane (eardrum). This is manifested by severe pain and often bleeding and deafness. Injuries to the inner ear are generally followed by deafness, tinnitus, and sometimes vertigo (sensation in which the individual or his environs seem to whirl dizzily). If blood and cerebrospinal fluid are draining through the external ear it is a sign of severe trauma, with cranial bone fracture and involvement of brain coverings (meninges) being almost a certainty.

Treatment

Lacerations and contusions of the auricle should be treated by thorough cleansing, hematomas (if present) should be evacuated under aseptic procedures, and a sterile pressure dressing applied.

It is best to place a thick, soft dressing over the mutilated ear, bandage it snugly, and make arrangements for evacuation of the casualty to professional care. If the external canal leading to the inner ear is torn or otherwise injured, the area should be cautiously and lightly packed with petrolatum-impregnated ribbon gauze and the patient evacuated.

Barotrauma and blast injuries in which the tympanic membrane is involved are generally extremely painful and accompanied by bleeding. No attempt should be made to clean out the ear canal or dislodge clots; neither should attempts be made to irrigate, pack, or administer ear drops.

NOSE INJURIES

Injuries to the nose are generally caused by blows, kicks, falls, or crushing, and result in nosebleed, hematomas and abscesses of the septum, and fractures. Fractures usually involve the nasal bone and one or both of the nasal processes of the superior maxillary bone.

Symptoms

Hematomas or abscesses of the septum often occur following trauma when hemorrhage occurs between the connective tissue covering the cartilage and the cartilage of the septum. Examination of the mucosa of the septum will show bulging and upon palpation the mass will be soft and fluctuant. Symptoms of fracture include nasal hemorrhage, pain, swelling, and usually some deformity. The deformity may show the bridge of the nose to be depressed or humped and pushed to one side. Alternate pressure of the index fingers applied gently along the nasal process on either side will reveal crepitus (grating of the fractured bones) and free movement of the bone.

Nosebleed (epistaxis) may occur spontaneously as well as from trauma, and since the two have much the same treatment, they are discussed concurrently, below.

NOTE

Following trauma, the escaping blood should be examined carefully to be sure that cerebrospinal fluid is not mixed with the blood, for if it is, the casualty should be placed in a prone position to facilitate drainage and no attempt should be made to check the flow.

Epistaxis occurring spontaneously will generally cease when a clot forms against the bleeding point. The insertion of a piece of cotton on the side of the bleeding is frequently effective in causing the formation of a clot, as is steady unrelenting compression of the nostrils between the thumb and forefinger for 4 or 5 minutes. Cold produces constriction of the blood vessels in the tissues at the site of reduced temperature and will also produce constriction of various distant points by reflex action. Therefore, application of a cold, wet cloth to the face and neck or the bridge of the nose is often effective, as is gentle aspiration of ice water.

For violent bleeding which cannot be controlled by methods given above, the casualty should assume a sitting position and be asked to blow his nose just enough to loosen clots and discharge them. Then with the head tilted slightly backward, he should inhale through the open nostril and exhale through the mouth. This should be repeated as rapidly as possible. This rapid transmission of dry air will control even copious bleeding.

In epistaxis due to trauma, generally the lateral wall of the nasal cavity or the septum will be sites of bleeding. A diver will rarely be called upon to resort to major procedures such as packing, since traumatic bleeding is usually mild. Other, simpler methods, outlined above, usually prove effective.

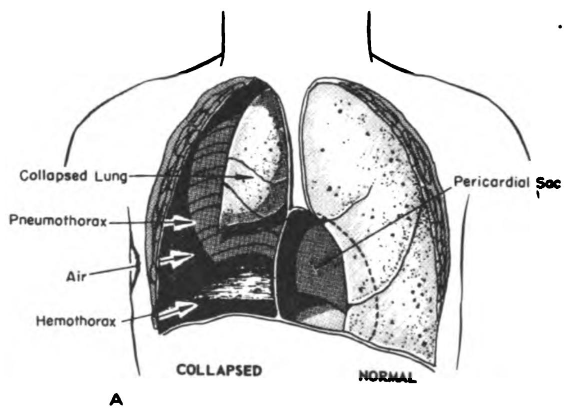
Fracture should be treated before swelling has progressed and especially before 48 hours have elapsed, as union will have begun.

CHEST INJURIES

Wounds of the chest may occur in a variety of combinations and involve wounds of the thoracic wall, ribs, pleura, the lungs, trachea, bronchi, esophagus, diaphragm, heart, and great vessels. Because of the peculiar physiology of the respiratory mechanism, large numbers of casualties with thoracic injuries die before medical aid can reach them. First-aid measures for chest wounds are limited, since professional care and surgical facilities are required to handle serious injuries of the area.

Symptoms

In most wounds of the lung, some air escapes into the pleural space. The term "pneumothorax" describes wounds in which the vacuum which allows the lungs to expand is broken by air escaping into the cavity; the air enters either by an external wound or a lung perforation (fig. A–19). A pneumothorax of considerable size can usually be diagnosed by reduced rib movement and reduction of breath sounds on the affected side. It is attended with sudden and severe pain and increasing dyspnea. When the pneumothorax is "open"—that is, the wound in the chest wall permits air to enter and leave the pleural space during respiration—a "sucking" sound is made and is diagnostic. The lung wound may be valvular, which means air entering the pleural space with inspiration cannot



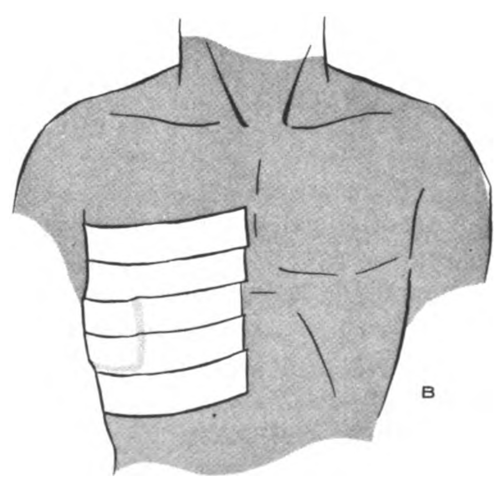


FIGURE A–19.—Diagrammatic sketch of penetrating chest wound. A, shows complications of airtight pressure bandage.

escape. As the pneumothorax increases in size, the wounded lung is compressed—this displaces the mediastinum to the opposite side and compresses the unwounded lung. This is called *tension pneumothorax* and can be recognized by the usual signs of pneumothorax, combined with displacement of the trachea and the apex beat of the heart to the opposite side. Dyspnea is pronounced, and there is cyanosis of lips and fingertips.

There is usually bleeding into the pleural cavity producing what is called *hemothorax;* this is manifested by coughing of frothy blood. Fractures may range from one rib, to the stove-in chest with double fractures of many ribs. Fracture of a single rib is generally manifested by sharp pain caused by breathing and resulting from grating of the bone fragments and partly from inflamed lining of pleura adjacent to the injury. With multiple fractures, the portions of the chest wall lying between these areas of fracture will not move in unison with the rest of the rib cage; generally associated are hemothorax, pneumothorax, and intense pain.

A wound of the heart in which the pericardium (membranous sac which contains the heart) is not involved is generally followed by bleeding which fills and distends the pericardium. *Cardiac tamponade*, as this condition is called, can be recognized by the small pulse and pulse pressure, and venous distention. If the blood is not released from the pericardium, death from circulatory failure is inevitable.

Treatment

The goal is to empty the pleural space and restore the normal pleural and pericardial negative pressures. A diver is limited in bringing about these objectives because they require a surgeon's skill and special equipment.

Chest injuries are often extremely painful. To stabilize a flail or stove-in chest, a diver may apply a firm pressure dressing over the mobile segment of the chest wall. To correct an open or sucking wound, an airtight pressure dressing may be applied over the wound. The gauze placed next to the wound should be slightly moistened, if this is possible. The dressing should be held in place by airproof adhesive strapping. In the nonperforating type of pneumothorax, the chest should be strapped with adhesive tape. (The tape should not completely encircle the chest; it should extend no more than three-fourths of the circumference.) The air in the pleural cavity will gradually be absorbed and the lung will expand.

The bronchial tree which often becomes obstructed with secretions as well as by blood must be kept clear. Obstruction often comes about because coughing is too painful to raise the sputum. Placing the casualty on the affected side with his head slightly lower may help him respond when he is asked to cough.

Evacuation to a medical facility should be arranged as promptly as possible. If fracture is a consideration, placing the patient on the injured side will help splint the moving chest cage and improve respiratory exchange. When shortness of breath is a problem, transportation in a semirecumbent position (head slightly raised) will help the breathing as well as diminish the venous distention.

Collections of blood and/or air in the pleural cavity (see "Symptoms" above) are conditions requiring aspiration by needle and large syringe (with a two-way adapter). The adapter avoids subjecting the intrapleural space to atmospheric pressures while each syringeful of blood or fluid is being emptied. Hemothorax, pneumothorax, and cardiac tamponade are conditions which require the specialized skills of the medical profession for treatment. Before attempting aspiration, advice should be sought from a medical officer via shortwave radio, telephone, or other communication facility.

ABDOMINAL INJURIES

Death following wounds of the abdomen is due primarily to hemorrhage, shock, or peritonitis. If the great vessels are involved in the wounding, fatal hemorrhage will result unless the casualty is brought to immediate surgical care. Wounds of the solid viscera, kidney, liver, and pancreas produce profuse internal bleeding plus chemical inflammation due to leakage of urine, bile, and pancreatic juice; wounds of the hollow viscera (stomach and intestines) produce delayed bacterial inflammation and the acid gastric juice also sets up great irritation of the peritoneum and often pain. But, whatever the cause, peritonitis can easily be fatal.

Abdominal wounds fall into two broad categories: *Penetrating*—from bullets, shell fragments, icepicks, and knives; and *nonpenetrating*—from collisions with objects such as furniture, blows from fists, blasts from high explosives, and from crushing accidents.

Symptoms

Diagnosis of penetrating injury is generally self-evident. High-velocity bullets often have a small point of entry but the wound of exit is large, due to explosive effect inside the body. However, small pieces of steel, glass, or stone may be hurled with great force as by power lawnmowers, explosives, and leave scarcely a discernible wound of entry. Also, the missile may enter outside the abdominal area, but lodge inside it, making diagnosis difficult. Pain is usually severe and accompanied by nausea and vomiting.

In nonpenetrating wounds, the injury to the internal abdominal organs and blood vessels may be masked by the symptoms produced by overlying injury, as intense pain caused by fractures of ribs will cover up symptoms indicative of injury to liver or spleen. Nausea and vomiting should alert the diver to the possibility of abdominal injury especially if the vomitus contains blood. Pain is another symptom; also abdominal tenderness to hand pressure and rigidity of overlying muscles. Tenderness is an indication of the location of the viscera involved, and muscle spasm indicates involvement of the peritoneum and aids in locating the injury. If there is contamination of the peritoneum (blood, contents of hollow or solid organs), there is usually a progressive spread of tenderness and rigidity first involving the quadrant, then neighboring quadrants, and finally the entire abdomen. There is rise in temperature and distention. These are the symptoms of peritonitis which demand professional care.

Shock (pallor; cold, clammy skin; rapid, thready pulse; low blood pressure) generally accompanies abdominal injury. Diminution or loss of peristaltic sound is indicative of paralyzed bowel (paralytic ileus), bleeding, or peritonitis. If there is extensive bleeding, there will likely be dullness to percussion in one or both flanks. This dullness will shift on change of position of the patient from one side to the other, or from lying down to sitting up.

Treatment

For optimum results, open wounds of the abdomen should receive surgical treatment at the first possible opportunity, preferably within 1 to 4 hours. The problem of first aid, then, is to keep casualties from bleeding to death. A diver administering first aid must also treat the shock

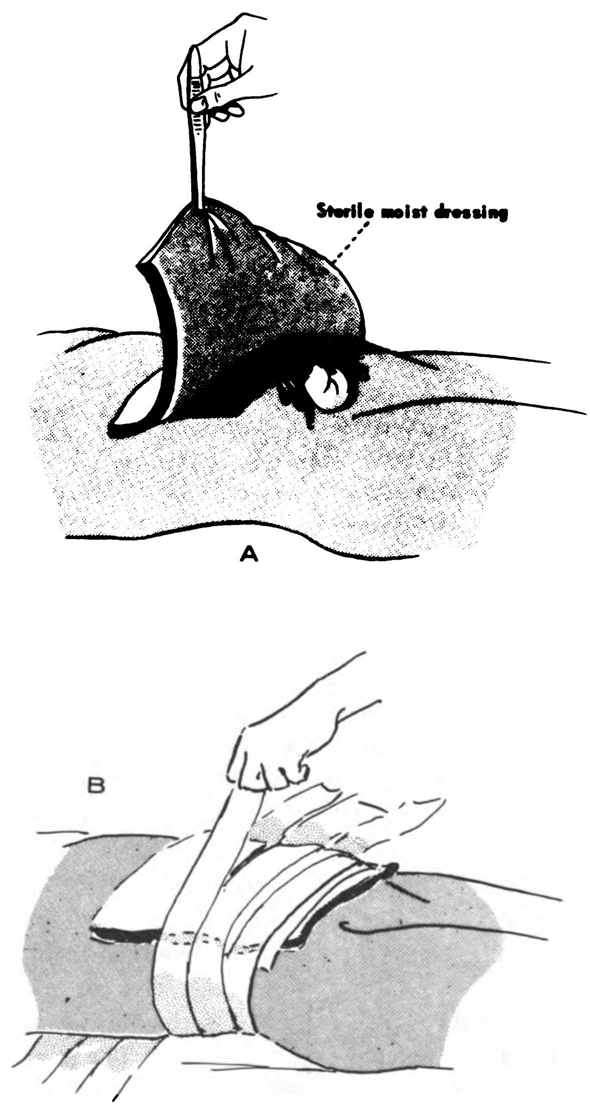


Figure A–20.—Abdominal wound with protrusion of intestine. A, shows application of sterile, moist dressing; B, application of scultetus (many-tailed) binder.

which almost inevitably follows, and deliver the injured to professional care in the best condition possible. If the bleeding vessel is in view, clamp it. If not, a bandage compressing the abdomen may help control the hemorrhage. This bandage should be a scultetus or many-tailed binder if one is available.

If the wound is open, it should first be covered with a sterile dressing over which is placed the compression binder. If organs or bowels protrude, make no attempt to replace them. Cover them with large, sterile cloths moistened with any sterile, nonirritating solution such as physiological saline, sterile water, or even blood. After covering, apply a compression bandage, but not so tightly as to interfere with circulation (fig. A–20). Give nothing by mouth—no food, fluids, or drugs. If this type of casualty is adjudged transportable, he will probably be more comfortable if both torso and knees are flexed.

In contrast to penetrating wounds, nonpenetrating wounds are not as dramatic; however, the wait-and-see attitude should never be employed. The victims of crush, blast, or intra-abdominal injury regardless of the cause, should receive a high priority for evacuation to professional care. A bandage compressing the abdomen may be applied to help suppress the hemorrhaging. Nothing should be given by mouth as this increases the activity of the stomach and intestines and will cause more spillage if the intestines are ruptured.

GENITAL INJURIES

Direct injury to the genitalia results as a rule from falling, direct blows, or shellfire.

Symptoms

Depending upon the severity of the injury, symptoms may be shock, intense pain (patient writhing in agony, hemorrhage, and hematuria (discharge of blood in urine). Also, there may be inability to void urine even though there is a strong desire to do so. Hematoma may develop rapidly, and fever and infection may appear later.

Treatment

Elevate the scrotum by placing a folded towel in the crotch, or by making an adhesive bridge under the scrotum from thigh to thigh. This is called a Bellevue bridge.

In the event of extreme injury to urethra or genitalia, distention of the bladder due to retained urine can be expected. This usually becomes a problem around 10 to 12 hours, or longer, after injury. For this reason, every effort should be made to get the casualty to professional care immediately. If, for some reason, evacuation cannot be accomplished within this time limit, radio for advice. The procedure for tapping the bladder to forestall its rupture is generally considered beyond the capability of paramedical personnel, but if the evacuation timetable seems to demand such a procedure to save a life, the physician contacted will make the decision and give the necessary instructions.

CAUTION

Injuries of this nature frequently catapult the casualty into shock. If this happens and his systolic blood pressure falls below 100 millimeters of mercury, then urinary output decreases and the method of treatment must assume another direction. Ask for advice!

INJURIES OF THE EXTREMITIES

Injuries of the extremities are frequent and range from minor cuts and bruises to traumatic amputations (avulsions). In a great many injuries, bone fracture is a possibility. Primary assessment of the injury should always be done with gentleness and before moving the casualty. When fracture is a consideration, splinting the fracture and transporting the injured person impose further demands upon the diver (see pertinent sections below).

Diagnosis

In checking injuries of the extremities, adequacy of the blood supply to the area beyond the injury should be carefully assessed. This is especially so if a major vessel has been lacerated and a tourniquet applied. The skin distal to the injury should be observed for warmth and color, and arteries should be checked for pulsation. Trouble with the blood supply can also be evaluated by applying pressure to a fingernail until it becomes pale, and then observing return of color following release of pressure. Shock is almost always a consideration in such casualties, and if the pulse rate is over 100, the systolic blood pressure less than 100 millimeters of mercury, skin pale or cyanotic—treatment for shock must be started.

Traumatic amputations are self-evident and require heroic measures to keep the casualty from bleeding to death or succumbing to irreversible shock.

Treatment

If the blood supply of an extremity is in jeopardy, the limb should be placed at the level of the trunk or slightly lower (never raised), and left exposed to cool (never freezing) air. Keeping the extremity cool tends to delay onset of infection. If the extremity is mangled, or if examination reveals a suspected fracture, pressure dressings should be applied to stem hemorrhage and then the extremity should be splinted before any movement takes place.

In traumatic amputations and in incomplete amputations, hemorrhage is of grave concern. If a pressure dressing is ineffective, a tourniquet may be necessary to stop bleeding. When it is applied, it should be placed at the lowest possible level and, when bleeding is controlled, the stump should be dressed with a voluminous pressure dressing. The extremity should then be splinted and elevated for transporting the casualty to professional care.

If a casualty being treated already has a tourniquet in place, it should not be released. A tourniquet should not be removed until professional care is available, and until the blood volume has been restored to a safe level. Loss of additional blood, even 100 milliliters can completely break down the delicately balanced compensatory mechanism and trigger profound or even fatal shock.

In injuries involving the *hand*, every effort should be directed to avoiding infection and additional tissue damage which will lead to stiffening and loss of delicate hand movements. Sterile dressings, if available, or a clean cloth should be used to cover the wound. A soft, bulky

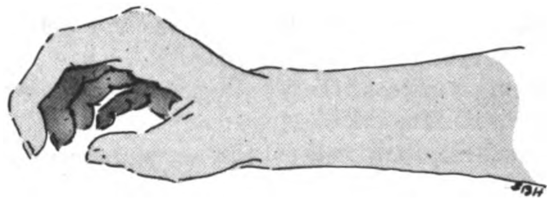


FIGURE A–21.—Position of function—hand.

pressure dressing should then be applied to control bleeding and minimize swelling. The pressure dressing should not be too tight, only "snug," for a constricting dressing will close off blood vessels. The fingers should be separated from each other and kept in a natural, curved position known as the position of function (fig. A–21).

The position of function usually maintains the most favorable relation of bone ends and prevents muscle contracture and joint stiffness which may occur when the hand is immobilized in a "flat" position. When the hands are severely burned or crushed, the same first-aid treatment should be given—the hand covered with a sterile dressing, immobilized in the position of function (gently placed over the Universal splint if one is available), covered with a moderately snug pressure dressing, and then elevated.

In injuries of the foot, effort should be made to bandage the foot so that it will remain at right angles to the leg (fig. A–22).

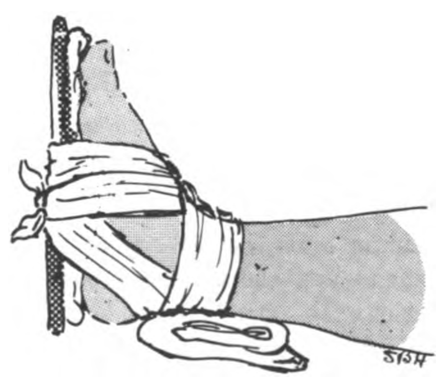


FIGURE A–22.—Position of function—foot.

A–D. BLAST INJURIES

The human body is not constructed to tolerate very marked increases in pressure as is obvious from experiences in deep-sea diving. Explosions produce a wave of pressure which can inflict serious damage to the human body; these injuries are categorized as blast injuries. There are several types of blast injuries: air-blast following bomb explosions; underwater blast from explosions of torpedoes, mines, and depth charges; and solid blast when pressure waves strike solid objects such as the wall of a tank or the deck of a ship. Without damage to the skin, pressure can produce fractures, disrupt major blood vessels, and damage internal organs.

Diagnosis

When a serviceman is encountered in the vicinity of an explosion (and there are no visible wounds or injuries from falling debris or flying objects) and seems to be in a state of shock, chances are he has been injured by the blast of the explosion. The victims of blast injury are often treated as walking wounded, and it is not until shock, labored breathing, and other symptoms appear that the correct diagnosis is made. Blast victims are usually nervous, apprehensive, and tremulous.

Blast may cause rupture of the tympanic membrane of the *ear*. Usually this is manifested by bleeding, bruising with congestion, pain, and loss of hearing. Blast injury of the *lungs* is characterized by shock, restlessness, cyanosis, rapid pulse, pain in chest and upper abdomen, cough, and shallow breathing. There may also be abdominal rigidity and ineffective expectoration of frothy, bloodstained mucus. In mild cases of blast injury of the *abdomen*, the casualty may complain of abdominal pain with tenderness and perhaps slight distention. Others may have pain with vomiting and frequent defecation. In more severe injuries, the stools may be dark or stained with blood pigments; the vomit may also be black and the urine may contain either bright-red blood (fresh bleeding) or dark "coffeelike" blood (older bleeding). Pain is severe and unremitting. In these casualties, perforation of the hollow viscus and internal bleeding should be strongly suspected.

Treatment

In treatment of ruptured eardrum, the opening (meatus) should be gently cleansed with dry sterile cotton wool, and the ear left alone. The ear should not be packed, and syringing and use of any drops are contraindicated.

In blast injury of the lungs, the casualty should be moved as little as possible and then on a litter. He should not be sent through a prolonged chain of evacuation before 48 hours have elapsed unless the tactical situation offers no other course. Pulmonary edema must be expected, and therefore fluid to replace lost blood is hazardous. Tracheostomy may be necessary in these casualties.

Treatment for abdominal blast injuries of a serious type requires operative measures, for peritonitis is a certainty if hollow organs have been perforated. These casualties should be placed high on the evacuation list. Foods and fluids by mouth should be restricted.

A-E. CRUSH INJURIES

Crushing accidents rarely occur in peacetime and then generally only in catastrophes such as earthquakes and mine or other cave-ins, but during wartime they occur frequently, especially during bombings when buildings and other structures collapse. Those with crush injuries to chest and abdomen often die before help arrives, but crush injuries to the extremities alone are not immediately serious and mainly become so later when kidney complications arise, or when liquid fat enters the circulation from ruptured fat cells or from bone marrow as can happen following fracture of the femur or tibia. This fat forms myriads of fat globules which embolize (plug) the pulmonary capillaries and capillaries in the brain, skin, and kidneys.

Diagnosis

When first freed from the site where pinned, the casualty may show surprisingly few manifestations of shock and have normal pulse and blood pressure. Soon afterward, however, the affected part swells because of the extravasation of plasma and red blood cells from damaged capillaries. Oligemic shock is thus precipitated, or, if already present, is aggravated. The blood pressure falls rapidly as plasma loss continues. The damaged part becomes swollen, tense, and hard. The distal pulses tend to disappear. Then a day or so after the accident, serious kidney "shutdown" (oliguria or even anuria) develops which may result in death. In favorable cases, the kidneys start functioning about 6 to 8 days after injury, but even though the casualty improves, kidney dysfunction may plague him for many months.

The clinical picture of those with fat embolism is rather characteristic. First there is a "free period" of several days, and then suddenly symptoms and signs of either pulmonary or cerebral irritation develop. The respiratory rate and depth increase and breathing may be stertorous in quality. Cerebral symptoms include restlessness and anxiety which may give way to delirium and then coma. In the absence of intracranial and intrapulmonary trauma, these symptoms are diagnostic. Also, characteristically fine, brownish petechiae (pinpoint intradermal hemorrhage) appear in the skin of the upper trunk, and fat globules may be found in the urine.

Treatment

The casualty who has been crushed often has other serious injuries and is losing blood. Restoration of circulating blood volume should be accomplished promptly before the kidneys become involved, for once there is evidence of acute renal insufficiency, administration of fluids is harmful.

Loss of fluid into the crushed tissues may be slowed down by application of an elastic bandage, but care should be taken not to apply the bandage too tightly lest it act as a tourniquet and obstruct all blood flow. The elastic bandage (the web type is best) should be applied from the distal part of the extremity proximally. The amount of pressure under the bandage should be equal to 40 to 60 millimeters of mercury. The limb should be splinted and kept cool. The casualty should be immobilized.

As implied under diagnosis, in crush injuries renal shutdown is the big problem. If the excretion of urine is considerably reduced, then the casualty should be given fluids. By mouth, 8 grams of sodium bicarbonate in 500 milliliters of water (2 teaspoonfuls to a pint) should be given.

NOTE

If the urine measurement is less than 25 milliliters per hour, then administration of fluids is contraindicated, for the kidneys are not functioning—at this time only peritoneal

dialysis with the proper dialyzing solution or an artificial kidney will help.

The best treatment of fat embolism is preventive: adequate emergency splinting, gentle handling of the injured extremity, and elevation of the limb. With the first signs of restlessness and cyanosis in the presence of adequate blood pressure, oxygen administered under pressure may prove of benefit.

If the extremity is so severely crushed that no blood supply is reaching the tissue, then ultimate amputation is all too often the only solution. Early evacuation to a surgical facility is mandatory.

A–F. HEAT INJURIES

BURNS

Diagnosis

Burns are classified in several ways: by the extent of the burned surface, by the depth of the lesion, and by the cause of the burn. Of these, extent plays the greatest role in survival.

In calculating *extent* of burned surface, the "rule of nine" is used (fig. A–23). These figures

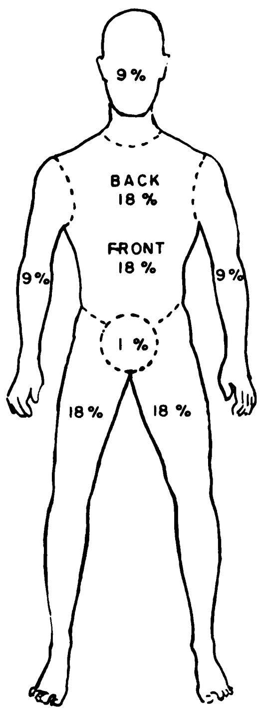


FIGURE A–23.—Rule of nine for estimating percentage of burned area.

aid in determining the correct treatment for the burned individual. In adults with burns of over 15 percent or small children with burns of over 10 percent of body surface area, shock can be expected. In adults, burns involving more than 20 percent endanger life, and 30 percent burns are usually fatal if adequate treatment is not received.

Depth of the lesion is spoken of in degrees (see fig. A–24) : *First-degree* burns are the mildest, involving only the outer layer of the epidermis, and producing redness, increased warmth, tenderness, and mild pain. *Second-degree* burns extend through the epidermis and involve the dermis but not enough to prevent rapid regeneration of the skin. They produce vesicles and blebs (blisters) and are characterized by severe pain. *Third-degree* burns are full thickness, destroying both the epidermis and dermis. Severe pain, characteristic of second-degree burns, may be absent because nerve endings have been destroyed. Color may range from white and lifeless (scalds) to black (charred from gasoline explosions). Healing occurs only after many months, and then with contracture and scarring. Skin grafts are generally required.

Causes of burns are generally classified as thermal and chemical, or as resulting from sunburn, electric shock, or radiation. Whatever the cause, if the burns are extensive, the body responds with shock. Early signs of incipient shock are increased pulse rate or fall in blood pressure, thirst, and restlessness. This progresses to the classic picture of shock—low blood pressure; weak, thready pulse; cold clammy extremities; confusion; and oliguria.

Burns of the respiratory tract are very serious and may be diagnosed by singeing of nasal hairs, cough, expectoration of blood or carbon particles, and swelling of larynx. Tracheostomy may be necessary. The electric shock which produces electric burns may also bring about paralysis of the respiratory center or convulsive movements of the heart known as ventricular fibrillation.

Treatment

First aid for all burns involves the following main items:

1. Relieve pain.
2. Prevent or treat shock.
3. Prevent infection through strict asepsis.

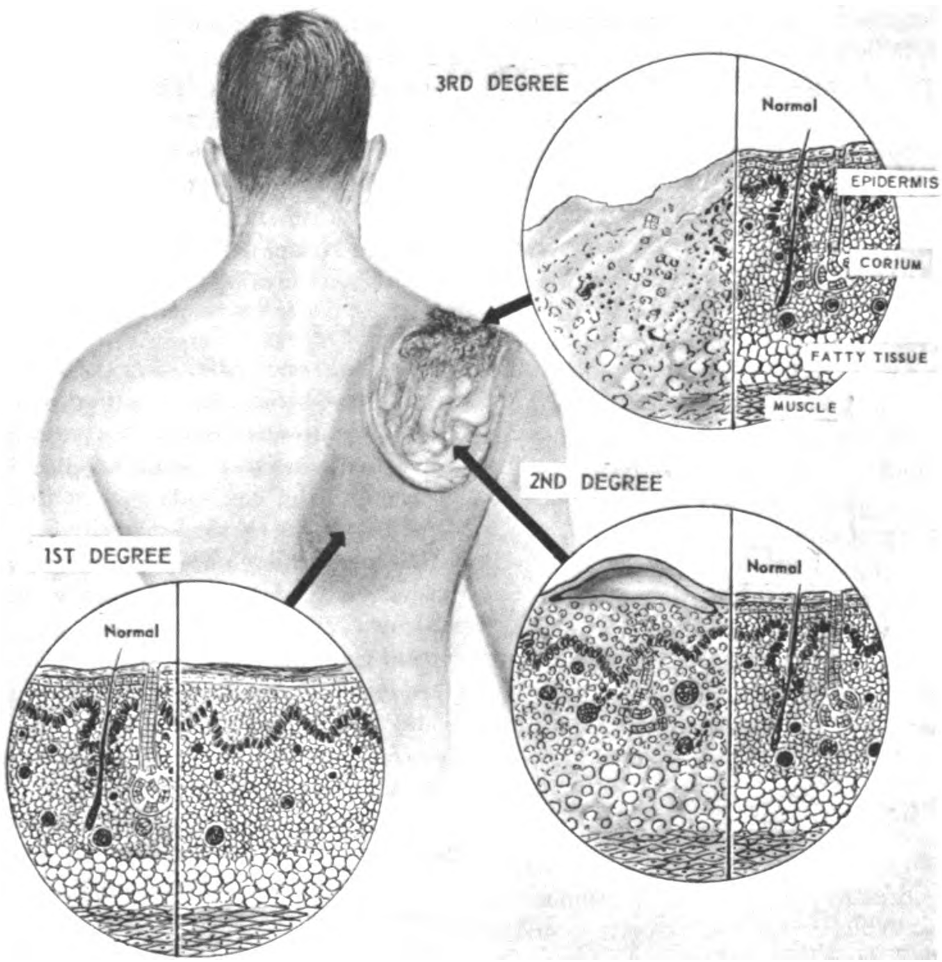


FIGURE A-24.—Degrees and types of burns.

In electric injury, the burn may have to be ignored temporarily while resuscitative measures are carried out (see "Methods of Resuscitation" for ways to restore breathing and restart the heartbeat). Otherwise, treatment is the same as for thermal burns. Also, local treatment of chemical burns varies with the agent. After washing the burn with large quantities of water, acid burns should be neutralized by washing with a dilute sodium bicarbonate solution, and alkali burns with vinegar or dilute acetic acid solution. Otherwise, treatment is the same as for thermal burns.

Ice-water treatment.—For burns involving less than 20 percent of the body surface, immersion of the burned part in ice water or the repeated application of ice-cold moist towels to areas where immersion is impracticable has proved to be a most effective method of primary management. It is recognized that clean water and ice cubes are not always available, but when they are, as an emergency measure, ice water provides immediate alleviation of burn pain and damaging sequelae also seem to be lessened. The treatment should be continued until no pain is felt when the burned area is withdrawn from the water. The time involved ranges from 30 minutes to as long as 5 hours. When available, hexachlorophene should be added to the water for its bactericidal effect. The regular regimen for burn management should then follow (see below).

Relief of pain.—Simple first-degree burns of limited extent may require no more than one or two aspirin tablets to relieve discomfort.

Fluid replacement.—After relief of pain, the next most important step in shock management is to replace the fluid which has been lost from the burn area to the edema which develops in the first phase of oligemic shock. (All burns of more than 10 to 15 percent of body surface are going to require fluid.)

Prevention of infection.—Whenever the epidermis is broken, invasion by bacteria is a possibility. Infection seems to be a frequent and early development, and its prevention should be ever present in the mind of the diver. Makeshift wrappings such as sheets and freshly laundered towels may be used to cover the burn and to keep out dust and dirt, but every effort must be made to use a sterile covering. Ointments and other medicines should not be put on the burn wound. When the casualty reaches the installation where he will remain for the next 24 to 48 hours and his pain has been relieved and shock treated, the burn wound should be dressed definitively.

EMERGENCIES DUE TO HEAT

When man exerts himself in a hot environment, a considerable part of his circulation must be directed into blood vessels of the skin in order to radiate heat from the surface and to support activity of the sweat glands. When the vasomotor control (nerves which control expansion and contraction of blood vessels) and cardiac output are inadequate to meet the needs of increased skin circulation in addition to muscle and cerebral circulation, the individual collapses. *Heat exhaustion*, therefore, is a physiologic disturbance following exposure to heat and is characterized principally by peripheral vasomotor collapse. It may be precipitated in even the most fit men by heavy enough work in a severe enough environment. Heat exhaustion is usually nonfatal. *Heat cramps* are painful contractions of various skeletal muscles brought about by the depletion of sodium chloride from the body fluids caused by excessive sweating. The cramps are most commonly associated with leg muscles and abdominal muscles in men working in temperatures above 100° F. Although heat exhaustion and heat cramps may coexist, the mechanisms by which they are produced are different.

Heatstroke has for its distinguishing manifestation an extreme elevation of body temperature. This is due to a failure of the sweating mechanism and it may occur whenever heat regulation is dependent upon sweating for a long period of time. Heatstroke calls for heroic measures to reduce body temperatures immediately to prevent brain damage and death.

Diagnosis

In *heat exhaustion*, faintness, usually with a subjective sense of palpitation, is the predominant symptom. Nausea, vomiting, fainting, headache, and restlessness are also common. The casualty who has collapsed in the heat and is perspiring freely almost surely has heat exhaustion. Even though his temperature may be somewhat elevated, sweating rules out the diagnosis of heat stroke. Under general supportive treatment the victim of heat exhaustion will usually recover consciousness promptly, even though he may not feel well for some time.

Heat cramps occur in paroxysms, most frequently of the flexors of the arms and legs. In the typical picture, the patient has his legs drawn up, is thrashing about, grimacing, and crying out from the excruciating pain. Examination will reveal spasms or knots of muscles, pale, wet skin, normal or only slightly elevated temperature and normal blood pressure.

Though diminution or cessation of sweating may precede *heatstroke* by several hours, onset is sudden. The patient may occasionally be aware of cessation of sweating, but often he is not. Sensation of extreme heat is his first indication. Weakness, headache, dizziness, mental confusion, staggering gait, delirium and coma are progressive symptoms. The victim appears flushed, his skin is hot and dry, and he is sometimes anxious, at other times listless. Early his pupils are contracted; later they dilate. Pulse rate may be 160 or more, respiration 20 to 30, and blood pressure may be slightly elevated. Temperature rise is phenomenal—sometimes to 105° to 106°, and even to 108° F. Temperatures above 106° are a grave prognostic sign, and above 108° irreversible changes in the brain can be expected. Convulsions, projectile vomiting, profound shock develop, and are followed by circulatory collapse and death.

Treatment

The prognosis of uncomplicated *heat exhaustion* is good. The casualty should be placed in a reclining position in a cool environment. Cool water containing 0.1 percent sodium chloride should be given by mouth.

The treatment of *heat cramps* is salt (and water), either in tablet form or as salted drinking water. Manual pressure on the cramped muscles may give some immediate relief. As is often the case, the best treatment is prevention, and heat cramps need not be a problem if personnel can be persuaded to take salt tablets or heavily salted table food when stationed in hot climates. One way to be sure of personnel receiving adequate salt is to add 0.1 percent sodium chloride to their drinking water.

The aim of treatment in *heatstroke* is to reduce body temperature to a safe range as rapidly as possible, for brain damage is the product of time as well as temperature. Total immersion in an ice-water bath is probably the most efficient method. Evaporative cooling by sprays and fans is effective if the environment is dry enough to allow rapid evaporation of the moisture. Vigorous massage of the extremities during cooling to overcome peripheral stagnation will bring about more rapid transfer of heat, combat vasoconstriction induced by the cold water, and hasten return of cooled peripheral blood to the brain. When the victim's rectal temperature reaches 102° F, he should be removed from the ice-water bath, but should be closely watched and his temperature checked every 10 minutes. Irregularity may be expected for several days and rapid cooling to 102° F should be the goal each time the temperature soars. It should be noted that recovery is slow, often taking several weeks. Bedrest is recommended for several days. Most of those who recover experience some intolerance to heat thereafter.

A–G. COLD INJURIES

Cold injury may be defined simply as tissue injury caused by exposure to cold. Although there may be several ways in which cold injuries occur, it is generally accepted that most of the tissue damage results from vascular impairment brought about by exposure to severe cold or prolonged cold. The severity of the vascular damage is directly related to the intensity of cold, duration of exposure, and such other factors as wind, wetness, constrictive clothing, dependency, immobilization, and trauma. Each of these factors either increases the intensity of cold or adversely affects circulation to the exposed part.

Traditionally, cold injuries are categorized as chilblain, immersion foot, trenchfoot, and frostbite (in order of ascending severity). However, these categories serve little purpose other than to describe the mode of injury. Basically, there are two types of cold injuries: *freezing* and *nonfreezing*. To find a "pure" injury, however, is infrequent. Rather, "graded" injuries are encountered, ranging from frostbite of the exposed part to lesser degrees of nonfreezing as progress is made toward less exposed parts.

Diagnosis

Early evaluation, even for an experienced medical officer, is difficult. Moreover, the involved area may present several degrees of injury without regard to a regular pattern of progression. Table A–1 attempts to show the times and temperatures involved in producing cold injuries and the symptoms which each level or type of injury can be expected to present.

Frequently cold injury is followed by sensitization to cold. With mild injuries, the sensitization may persist only for a few days or weeks, but in more severe injuries it may be permanent. Cold sensitivity in certain cases may be termed as an allergy and upon exposure to cold the part may demonstrate urticaria (hives) with intense burning, itching, and swelling. Indeed, in some, exposure may cause a systemic reaction of generalized urticaria, asthma, and even shock.

Treatment

Cold injury should never be treated lightly because of the tissue loss and nerve damage which are frequently associated. When a diagnosis of cold injury is made, the patient should be restricted from his usual activities until the severity of his injury can be determined. First-aid measures, in general, consist of giving mild stimulants such as tea or coffee, exercising care not to injure anesthetized skin when removing constrictive clothing or gear and, negatively speaking, prohibiting alcohol and tobacco, or application of snow, ice water, grease, massage, or dry heat. Great care must be exercised to prevent infection and any blisters or blebs should not be broken. If the part has been frostbitten, it should be rapidly rewarmed in a controlled-temperature water bath.

Very mild cold injuries, such as *chilblains*, require little specific treatment. However, because of the slow progression of tissue damage, care must be taken not to underestimate the cold injury.

Nonfreezing injuries such as trenchfoot and immersion foot should, in general, receive identical treatment. Blisters and blebs should not be ruptured, and salves and ointments should not be used. If the tissues are not macerated, the extremity may be left exposed without a dressing unless, of course, transportation is going to be necessary, in which event the part should be covered with loosely wrapped, fluff bandages of sterile gauze. When the tissues are macerated and infection and tissue loss seems probable, the extremity should be placed on sterile drapes and covered by a cradle also made of them to protect the sensitive tissues from pressure. A high-caloric, high-protein diet with additional

TABLE A–1.—*Causative factors and symptoms of cold injuries*

Classification of injury	Time and temperature factors [1]	Symptoms
1st degree:		
Chilblains Pernio	Repeated exposure, several hours at a time, to temperatures between 32° [2] to 60°; generally associated with high humidity.	Redness and swelling; itching, burning dermatitis; tingling, and later deep-seated ache.
2d degree:		
Immersion foot	Exposure to cold water (50° and below) 12 hr or more; or, to water of approximately 70° for several days. Immobilization, dependency.	Swelling legs and feet, cyanosis, numbness, tingling, itching, blisters, pain, neuromuscular changes.
Trenchfoot	Exposure to cold (32° to 50°), damp weather several hours to 14 days (average 3 days). Dependency, immobilization, constrictive clothing.	Part blanches, tingles, then becomes numb. Swelling legs and feet; cyanosis; blisters; intense burning pain; neuromuscular changes.
3d degree: Frostbite	Generally, brief exposure to extreme cold (−20° and below), or exposure to approximately zero weather for several hours.	First burning, stinging, then numbness. Ice crystals in skin cause gray or white waxy color. Skin will move over bony prominences. Edema; blebs; aching pain requiring medication; limitation of motion. Later gangrene, loss of tissue.
4th degree: Freezing	Exposure to −20° to −60° and below. May happen rapidly to exposed fingers and toes with extension as exposure is prolonged.	Ice crystals in entire thickness of part including bone, indicated by pallid, yellow, waxy color. Skin will not move over bony prominences. Edema; large blebs; intense pain; loss of motion. Later gangrene, loss of part.

[1] Time and temperature factors are not to be considered as exact as there are many elements which contribute to the speed of cooling—notably wind velocity. For example, given a temperature of 35° with a wind of 20 mph, the effect on all exposed flesh would be the same as −38° with no wind (just as in a deep freeze).

[2] All temperatures are given in degrees Fahrenheit.

vitamin B complex and vitamin C (500 mg per day) is recommended.

If *frostbite* or *freezing* has occurred, the extremity should be rapidly thawed in a water bath of 42° C (107° to 109° F), *provided* the part is not going to be subjected to extreme cold again during a long and difficult evacuation. (Refreezing a thawed extremity seals its fate, and it is better to leave the part frozen until the patient arrives at an installation equipped to care for it than to take a chance on refreezing.) Rapid rewarming in a water bath with thermometer control is the only safe and effective method; warming should not be continued beyond the time when thawing is complete. All such patients with involvement of the lower extremities must be treated as litter patients (no walking permitted) and the affected part should be slightly elevated.

Intense pain may ensue from rapid thawing. There are no contraindications for pain medications.

Great care must be taken to avoid further trauma and infection, and toward this end even the bed clothing must be supported so as not to touch the injury. The temperature of the room should be comfortably warm (72° to 78° F). Twice daily for 20 minutes the injury should be subjected to treatments in a whirlpool bath to which pHisoHex has been added. The gentle debridement and cleansing action of the water will minimize maceration and infection. If a whirlpool is not available, a basin in which the water is agitated by hand may be substituted. Under no circumstances should the injury be scrubbed or washed with any solid material.

Diet should be the same as that given under nonfreezing injuries. Arrangements should be made for evaluation by a medical officer at the earliest possible date.

GENERAL HYPOTHERMIA

Occasionally a victim of abnormal lowering of general body temperature (hypothermia) may have to be treated. Such a condition is generally brought about by total immersion in cold water and loss of consciousness (perhaps through injury, coma, or alcoholism) in winter weather with prolonged exposure in inadequate clothing.

Diagnosis

The patient appears pale and comatose and may be taken for dead. Respirations are reduced in frequency and are shallow, pulse is faint or unpalpable (cannot be felt), and blood pressure may be unobtainable. Pupils do not react to light but are not dilated. Tissues feel semirigid and passive movements may be difficult.

Treatment

The first consideration is to bring the body temperature up to normal. This should be done by wrapping the patient in warm blankets and placing him in a warm room. Hot drinks, massage, and stimulant drugs are not indicated until after the patient has recovered consciousness. Oxygen *is* indicated. As the victim's temperature rises, he gradually becomes responsive, and at this time it is advisable to encourage deep breathing and occasional coughing. During recovery cardiac arrhythmias and ventricular fibrillation are the greatest immediate risk. Closed-chest cardiac massage may be necessary until arrival of a physician or his advice can be sought.

A-H. POISONED WOUNDS

SNAKEBITE

Two families of poisonous snakes, the *Crotalidae* and the *Elapidae*, are present in the United States. The *Crotalidae* are abundant and include the true rattlesnakes, the pygmy rattlers, copperheads, and water moccasins (cottonmouths). The family *Elapidae* has only one representative—the coral snake. The venom of the *Crotalidae* (frequently designated the "pit viper" family) is hemotoxic; it acts on the lining of the small blood vessels enabling blood to escape into the tissues. The venom of the *Elapidae* (coral, cobra, kraits) contains a highly potent neurotoxin. In addition, some venom contains a hemolysin and cardiotoxin.

Antivenin first became available in the latter part of the 19th century, and since that time many lives have been saved each year by its timely administration. The Armed Forces Medical Supply provides an antivenin kit which neutralizes the venom of hemotoxic reptiles of North and South America, including the rattlesnake, cottonmouth, copperhead, fer-de-lance, and bushmaster. *And*, around the world, antivenins have been developed which neutralize the venoms of the snakes peculiar to local areas. When identification of the biting reptile is made, or when symptoms develop which indicate the type of snake delivering the bite, the nearest installation from the list below can be contacted for a supply of antivenin and advice on management.

Worldwide Sources of Antivenin

Africa, South:
FitzSimon's Snake Park Laboratory
Durban, South Africa

Institute for Medical Research
Johannesburg, South Africa

Africa, North:
Institut Pasteur d'Algerie
Algiers, Algeria

Algeria:
Institut Pasteur d'Algerie
Algiers, Algeria

Australia:
Commonwealth Serum Laboratories
Melbourne, Australia

Austria:
Serotherapeutisches Institut Wien
Triesterstrasse 50
Wien X, Austria

Brazil:
Instituto Pinheiros
Rua Teodoro
Sampaio, 1860
São Paulo, Brazil

Instituto Butantan
Caiza Postal 65
São Paulo, Brazil

Burma:
Burma Pharmaceutical Industries
Rangoon, Burma

Colombia:
Nation 1 Health Institute
Bogota, Colombia

Egypt:
Agouza, Egypt

France:
Institut Pasteur
Service de Serotherapie
36 Rue du Doctor-Roux
Paris, France

Germany, West:
Behringwerke Aktiensgesellschaft
Marburg-Lahn, Germany

India:
Haffkine Institute
Parel, Bombay, India
Central Research Institute
Kasauli, India

Indonesia:
Gedung Tjatjar Den Lembaga Pasteur
Kotak Pos 47
Bandung, Indonesia

Iran:
Razi Institute
Hessarak-Karadj, Iran

Italy:
Instituto Sieroterapico
Milan, Italy

Japan:
Institute for Infectious Diseases
University of Tokyo
Shiba Shirodare-Daimache
Minato-Ku, Tokyo

Pakistan:
Pakistan Bureau of Laboratories
Karachi, Pakistan

Philippines:
Alabang Serum and Vaccine Laboratory
Manila, Philippine Islands

Taiwan:
Taiwan Serum-Vaccine Laboratory
Taipei, Taiwan

Thailand:
Queen Saovabha
Memorial Institute of Thai Red Cross
Bangkok, Thailand

United States:
Armed Forces Medical Supply
Antivenin Kit, Polyvalent
FSN 6505–680–2987

National Institutes of Health
Public Health Service
Bethesda, Md.

Wyeth Laboratories
Philadelphia, Pa.

Serpentariums of zoos
Large U.S. cities

Yugoslavia:
Central Institute of Hygiene
Zagreb, Yugoslavia

As mentioned, identification of the biting reptile should be established if at all possible. In some instances, recognition is not so easy because identifying characteristics vary with locality; this is particularly true of coloration. In addition, much false information is circulated as, for example, "snakes which are poisonous all have triangular heads." This is not necessarily true—some in which the head cannot be differentiated from the neck are dangerously poisonous. In identifying the reptile, these points should be checked:

1. *Arrangement of teeth* (fig. A–25).—The presence of fangs immediately labels the reptile as poisonous. In addition, the type of fang and its placement may provide a means of deciding its group.

2. *Rattle.*—Presence of rattles immediately identifies the rattlesnake. However, rattles are frequently lost and their absence need not rule out this family of reptiles.

3. *Sensory pit.*—Certain groups have a sensory organ between the nostrils and eyes placed in a "pit" and those with it are known as "pit vipers." All pit vipers, of which the rattlesnake and bushmaster are representative, are poisonous.

4. *Color and pattern of coloration.*—Since color and pattern change with age and from specie to specie and from locale to locale, they are not always reliable but do help in identification and should be fixed in mind. One generali-

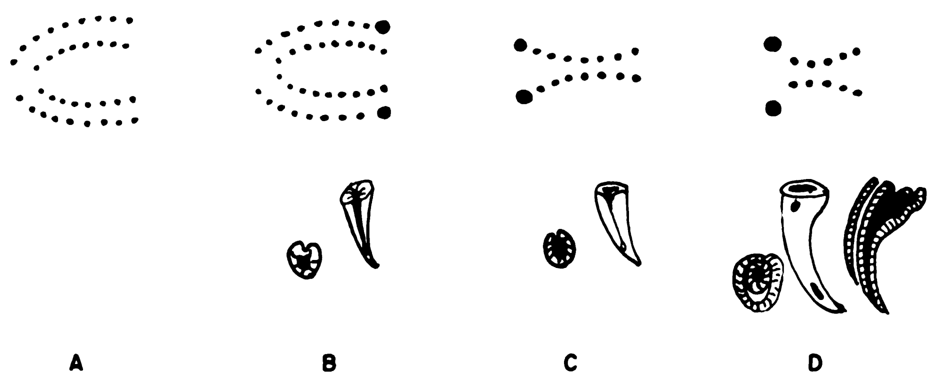


FIGURE A–25.—Identification of snakes by bite impressions. A, nonpoisonous, no fangs; family *Colubridae*, subfamily *Colubrinae* (U.S. garter snake, European ringed snake, black snake); B, poisonous, posterior fangs, fangs not hollow, but grooved slightly, family *Colubridae*, subfamily *Boiginae* (boomslang of Africa); C, poisonous, anterior fangs, fangs relatively short, deeply grooved, family *Elapidae* (kraits, mambas, water cobras, cobras, and coral snakes) and family *Hydrophidae* (sea snakes); D, poisonous, anterior fangs markedly separated from teeth, fangs long, relatively large, and completely hollow, family *Viperdae* (horned, sand, and tree vipers, puff adders), family *Crotalidae* (rattlesnakes, copperheads, water moccasins, fer-de-lance).

zation can be made, however; longitudinally striped snakes are not poisonous (there is only one exception: a small, very rare type native to the Far East).

Diagnosis

The bite from the *Crotalidae* is primarily *hemotoxic* and the symptoms which may occur are—

1. Tissue swelling at the site of the bite gradually spreading to surrounding areas. (Swelling occurs between 3 to 5 minutes following bite, but may continue for as long as an hour and be so severe as to burst the skin.)

2. Excruciating pain at site of the bite.

NOTE

Extreme pain is not characteristic of neurotoxic venoms.

3. Extravasation of blood from capillaries whose walls are destroyed by action of hemorrhaging. This accumulation of blood in tissues may cause throbbing pain.

4. Severe headache may follow internal bleeding, and thirst also usually follows as a result of the decreased blood volume.

5. Bleeding from some of the internal organs into digestive and excretory tracts may show as blood in urine and/or stool.

The bite from the *Elapidae* (cobra, coral, krait) is primarily *neurotoxic* and the symptoms which may occur are as follows:

1. Irregular heartbeat, drop in blood pressure followed by generalized weakness and exhaustion, terminating in shock.

2. Severe headache, dizziness, blurred vision or blindness, hearing difficulty, mental disturbances such as incoherent speech, stupor, mental confusion, and possibly unconsciousness.

3. Muscular incoordination, such as inability to reach out and pick up an object or move from place to place; sometimes muscle spasms and twitching.

4. Difficult or labored breathing and even respiratory paralysis.

5. Numbness and tingling of the skin particularly of the lips and soles of the feet, excessive perspiration, and sometimes salivation.

6. Chills and fever.

7. Nausea, vomiting, and diarrhea.

NOTE

Venom of sea snakes is neurotoxic, but since the bite is painless and does not swell, there ordinarily is no clue that first aid should be instituted. Poisoning should be suspected, however, if those who have been in coastal waters frequented by seasnakes complain within an hour of muscle aches, pains, and stiffness, or within 1 to 2 hours, there are pains on passive movement of arm, thigh, neck, or trunk muscles. And finally, within 3 to 6 hours, the urine shows red-brown.

Treatment

First advice to give the snakebite victim is to lie down and keep his emotions under control. The rescuer should remind the victim that of those bitten, few die or are even disabled if certain principles are followed. Since the identity of the snake is important to selection of the antivenin, kill the snake (one sharp blow on the head is the best method) and with a stick examine the mouth for fangs. Fix the color and pattern of color and general configuration of the reptile in the mind. Unfortunately, figures collected worldwide show that most snakebites occur between twilight and daybreak when snakes are most active and identification most difficult. Identification, in these situations, can only be made by analyzing the symptoms.

The following rules of first aid should be observed:

1. Immediately immobilize the bitten part and keep it in a dependent position below the level of the heart. Keep the victim dry, warm, and quiet. Transportation should be by litter if at all possible.

2. When the bite is delivered to an extremity, place a lightly constricting band or tourniquet 2 to 4 inches closer to the heart than the site of the bite. The band should be tight enough to stop the flow of blood in veins but not in arteries.

EXCEPTION

If the bite occurs in Africa, India, Burma, Thailand, or Australia where neurotoxic venoms are to be expected, or if the snake is positively identified as one possessing this type of venom, the tourniquet should be tight enough to restrict arterial flow and should be placed on the upper arm or upper leg where single bones make restriction possible. The tourniquet should be released for 30 seconds every 20 minutes to allow fresh blood to enter the extremity.

3. If more than 1 hour is going to elapse before antivenin can be injected, then the rescuer should employ incision and suction. With a sharp, sterile instrument (sterilized with a match if no other method is available) make two cuts, each not more than one-half inch long and one-fourth inch deep, through the skin over the fang marks *parallel to the longitudinal line of the extremity.* The incision must not enter muscles or injure underlying structures as tendons, blood vessels, or nerves. Suction may be performed by suction cup, if available, or by mouth, and continued for at least 30 minutes. The sooner it is started the better, for the chance of removing significant amounts of venom is reduced with the passage of time. If as much as an hour has elapsed since the bite was inflicted, this method should not be employed.

NOTE

Incision and suction, though done early, are no substitutes for injection of antivenin.

4. Administer antivenin as soon as possible. This is best done by a physician because of the difficulties which can arise from the horse serum contained in the antivenin, but if professional help is not available or is not going to be available, a diver should certainly proceed to try to save a life.

First he should inject 0.1 milliliter of the antivenin subcutaneously and observe the victim for at least 15 minutes for symptoms of allergy (itching, excessive sweating, swelling, and redness at the site of injection). If these symptoms do not occur, the antivenin should be given in one dose at a site other than that surrounding the bite. If these symptoms do occur, inject 0.3 to 0.5 millimeter of adrenalin subcutaneously and also be prepared to administer artificial respiration because shock may ensue from the horse serum. If the victim still exhibits allergic symptoms after the injection of adrenalin, then a decision must be made. If there is no doubt but that an effective bite has been delivered by a very dangerous species and that the victim will surely die without antivenin—then by the intramuscular route, in divided doses, inject the rest of the 1 millimeter of antivenin very slowly. If any sign of anaphylaxis (serum sickness) develops, the administration should be stopped.

5. Institute mouth-to-mouth resuscitation and cardiac massage if appropriate. In certain unfortunate situations (no antivenin available, no one who can go for help, incision and suction seems not to have retrieved much of the poison), it may be necessary to keep the victim alive by either of these two methods or their combination. There are a number of cases on record where men have been kept alive as long as 2 hours following onset of coma and been saved by delayed injection of antivenin. If respiratory paralysis develops, tracheostomy is indicated. Smoky fires, flashlight, flares, gunshots—all possible means should be used to attract attention for help.

WHAT NOT TO DO:

Alcohol is forbidden—it speeds up metabolism.

Icepacks, ice water, spray ethyl chloride have no proven value and may do considerable damage. Do not use.

Self-aid for snakebite.—The first point to keep in mind is that a nervous or frightened person is severely handicapped, so keep the emotions under control. If it is possible to kill the snake and look for fangs without a lot of activity and excitement, do so. If it is not, sit down at once, apply a tourniquet 2 to 4 inches above the site of the wound, incise the wound, and suck to remove the poison. Remain as quiet as possible and keep the wound lower than the heart.

If pain is significant, if there is swelling, numbness, tingling, or continued oozing of blood at the bite site, you can assume the snake was poisonous. Do not attempt to travel unless it is evident that no one is going to be coming for you—then walk slowly with a minimum of exertion toward help.

ANIMAL BITES

Bites inflicted by dogs are perhaps the most frequently occurring of the animal bites, but also of concern and requiring medical attention are cat, rat, squirrel, fox, and bat bites.

The prime concern in all animal bites is the possibility of the development of rabies, a fulminating encephalitis which is invariably fatal. If the biting animal can be captured, it should be impounded for observation. Signs of rabies will be unmistakable within 48 hours of the biting or, if the animal should die, the brain tissue will reveal Negri bodies. An impounded animal should be held for an 8- to 10-day period for safety's sake. If the animal disappears but the circumstances surrounding the biting indicate that the animal was not provoked but bit compulsively, administration of antirabies vaccine is a must. Bats have become infected to the point that any bat bites must be considered infective. Epizootics among foxes have become troublesome in some rural communities and no bite from these or other shy forest creatures such as squirrels should ever be neglected.

Treatment

There is no known effective treatment for *established* human rabies. Fortunately, however, there is a rabies vaccine available and it is on the supply table. The vaccine *must be administered* to anyone bitten by an animal suspected of being rabid. It is given subcutaneously into the abdominal wall daily for 14 consecutive days.

Recent articles appearing in the literature have stressed that prompt local treatment of all wounds inflicted by rabid animals is often decisive in blocking the spread of the rabies virus to the central nervous system, and may even kill the virus on the spot. Scratches, lacerations, or superficial bites inflicted by a rabid animal should be washed with tapwater and soap, or water to which a suitable chemical substance as hexachlorophene has been added, or should be swabbed or washed with antirabies serum. These measures can appreciably reduce the risk of rabies infection, and are particularly important if there is to be a delay in getting the victim to a doctor.

Treatment of dogbite in which rabies is not suspected is relatively simple, since there are few pathogenic bacteria in a dog's mouth. Most dogbites are penetrative with some minor laceration not requiring suture; occasionally, however, suture is required, especially if the laceration is about the face. In any event, the laceration should be gently irrigated and covered with sterile gauze. The services of a physician who can suture the tear should then be sought. From the standpoint of transmitting infection, bites of cats are serious because of the pathogenic bacteria they harbor in their mouths. Also, catbites are generally puncture wounds with inadequate drainage of the depths and little bleeding. Treatment consists of washing the area, applying sterile dressing, and immobilizing the part.

The bite of the rat can transmit a fever, called Sodoku by the Orientals, as well as other types of disease.

FISH BITES AND STINGS

Sharks

Shark and barracuda bites generally result in the loss of large amounts of tissue. Prompt and vigorous action to control hemorrhage and shock is necessary to save life. Bleeding should be controlled with pressure dressings if at all possible. If not, tourniquets may be resorted to. The wound should be irrigated to remove any debris and dressed with a sterile dressing which should be left undisturbed for 4 to 6 days. Arrangements for early evacuation to professional care for skin grafting or primary closure should be made.

Fish stings

Symptoms seem to run the gamut of sensations and range from burning, stinging, erythema, swelling, urticarial eruptions, formation of pustules, abdominal cramps, numbness, dizziness, pain in groin/armpits, nausea, muscular pain, difficulty in respiration, and constriction of chest, to cardiac weakness, prostration, and shock.

For *Portuguese men-of-war* stings remove tentacles immediately and wash skin surface with alcohol, then apply calamine lotion or ammonia water. For *jellyfish*, treatment is about the same; apply ammonia water, vinegar, or soothing lotion. Artificial respiration and cardiac stimulants are sometimes needed.

The wound produced by the *stingray* should be irrigated immediately with cold salt water. Much of the toxin will wash out, and, in addition, the cold water serves both as a vasoconstrictor and mild anesthetic agent. The part should then be immersed in hot water for 30 minutes to an hour. The water should be maintained at as high a temperature as the casualty can tolerate without injury (hot compresses can

370-711 O—70——29

be applied for wounds in areas not lending themselves to immersion). A sterile dressing should be applied after the soak.

NOTE

In experimental studies, heat has proved to have a deactivating effect on the pain-producing fraction of the venom as well as other known toxic components. Hot-water soaks which have been used since antiquity in many parts of the world are recommended for stings of many sea creatures such as scorpionfish, weeverfish, toadfish, catfish, venomous sharks, rays, and ratfish.

In management of fish stings, pain may be intense and relief necessary.

INSECT BITES

Spiders

The most common of the serious insect-type bites are those inflicted by the *female black widow spider*. The venom is neurotoxic and, within 15 to 30 minutes, abdominal muscular rigidity, becoming boardlike, and abdominal cramps begin. Only the absence of nausea and vomiting and "slight" tenderness in the abdominal region distinguish the signs from other abdominal conditions requiring immediate surgery. Weakness, tremor, and excruciating pain in the limbs usually develop. Labored breathing and speech, stupor and delirium, and convulsions may occur. Calcium gluconate (10 milliliters of a 10-percent solution injected slowly, intravenously) has been abundantly confirmed as effective in relaxing the muscle spasm, and warm-water baths also may aid in allaying the pain. Local measures are limited. Excision and suction are of no avail, but simple cleansing of the bitten area with application of mild antibacterial agents such as alcohol—to rid it of bacteria carried there by the usually dirty spider—is recommended. Convalescence may last for weeks with muscular weakness, and numbness and tingling of limbs. Repeated calcium gluconate injections should correct these symptoms. Prognosis depends upon maturity of the spider and age and physique of victim.

The *brown house spider* produces severe local pain, restlessness, fever, rash, and sometimes hemolysis by its bite. At the bite site a necrotic lesion develops which leaves a deep purple scar.

Bees, wasps, hornets, ants

Toxins common to this group are similar to venom of the viperine type of snake in having a hemolyzing factor, but they also contain histamine. Discomfort can be reduced by prompt application of strong household ammonia solution. In those who are allergic to this group of insects, stings about the head and neck can produce such swelling as to occlude breathing. Tracheotomy may be necessary. Prompt administration of oxygen and of artificial respiration is often appropriate.

A-I. FOREIGN BODIES

Foreign bodies in the eye

For a discussion of removal of foreign bodies from the eye, see "Eye Injuries" under "Management of Regional Wounds and Injuries."

Foreign bodies in the ear

Wax is a usual ear problem confronting divers, and in some individuals wax forms and hardens rapidly. It can usually be removed by irrigating with warm boric acid solution. If the wax is stubborn, it may soften with the use of a few drops of hydrogen peroxide or glycerine and then be removed, after a few hours, by irrigation. If wax still remains, this procedure may be repeated daily for several days, but eventually all the hardened wax should soften. Care must be exercised not to injure the ear by using other than a regular ear syringe, and the water should always be tepid and delivered to the ear in gentle rather than forceful stream.

Insects which get into the ear are especially annoying. Put two or three drops of ether into the ear and then irrigate with warm boric acid solution. Or, two or three drops of light oil or kerosene may be used if ether is not available.

If the foreign body is of vegetable origin such as pea, bean, or rice, do not syringe with water or boric acid solution as this will only cause the body to swell. If it is visible, it may be removed with a fine-wire curette; if it cannot be seen, resist probing into the ear but get the patient to a medical officer.

Foreign bodies in the throat

Fishbones, masses of food, or other objects such as false teeth may become lodged in the throat. When the foreign-body obstruction is known or suspected, the throat should be diligently explored with the finger to try to effect removal (sometimes a bite block may have to be improvised to prevent the victim from biting the exploring finger). Masses of lodged food may generally be removed in this fashion, and this is especially so because the maneuver generally causes vomiting and the food may be ejected with the vomit. If the foreign body lies in the bronchi and is causing breathing difficulty, place the victim over a chair seat or bench with head lower than the body and strike a sharp blow between the shoulders (small children may be picked up by the heels and slapped on the back). This often dislodges the object.

If these maneuvers do not dislodge the object but the victim is not having trouble breathing, make arrangements for his evacuation to a medical facility where the object can be removed by a physician. However, if the object *is* blocking the airway and his efforts to breathe are met with total resistance, then more valiant measures are going to be required, or the victim will die. If efforts to breathe result in retraction of intercostal spaces and stridor (a harsh whistling sound), and other signs indicate the victim is in extremis, then tracheostomy is probably the only lifesaving method available. This technique can be very dangerous and a diver undertaking it must be very sure of the anatomy of the neck and each step of the procedure. (See "Emergency Tracheostomy" under "Maxillofacial and Neck Injuries," for details.)

Foreign bodies in the stomach

Most foreign bodies which are swallowed into the stomach are generally round and smooth (pennies, dimes, marbles) and these readily pass through the intestinal tract without producing harmful effects. Occasionally, the swallowed object is pointed or sharp such as an open safety pin, a thorn, glass, among others. Although some of these may also pass safely through, there is a possibility that pointed objects may lodge and penetrate the wall of the intestine causing abscesses, or that cutting objects may slice the wall resulting in a general peritonitis.

Treatment need not be of an emergency nature, but the patient should be evacuated to professional care if the object had a sharp point or cutting edge. Otherwise, do not give laxatives of any nature for this increases peristalsis, thereby precipitating penetration of the sharp objects, but rather give the patient bulky foods to eat, such as bread, potatoes, and bananas.

Foreign bodies in the skin

Perhaps the most common foreign body with which the diver will be confronted is the *splinter*. To remove a splinter, first secure a sterile needle or knife point (may be held over a match flame to sterilize) and then clean about the area of the splinter. If the area is very dirty, clean first with a solvent such as benzene, and then follow it with a soap-and-water cleanse. Proceed to remove the splinter, and afterward cover the spot with a small sterile dressing.

If the splinter is embedded under a finger or toenail, cut a notch in the nail to expose the end of the splinter, then draw it out with forceps.

Some objects such as a *needle* or *fishhook* may be pushed through the part and removed. In the case of the barbed fishhook, the hook is pushed through until the barb is exposed; the barb is then snipped off and the barbless fishhook pulled through the flesh.

If a needle is broken off in the depths of the foot, make no attempt to extract it. Immobilize the patient (walking causes the needle to migrate, making removal much more difficult) and evacuate to professional care.

Rings on swollen fingers can usually be removed with soap or petrolatum. If necessary, a wirecutter or file may be used.

A–J. INJURIES OF MUSCLES, JOINTS, AND BONES

Injuries to the extremities have accounted for a large percentage of battle casualties in all the wars of history. Studies of automobile and industrial accidents also reveal an appreciable number of extremity injuries, with spinal injuries ever increasing. It is important to be able to recognize these, and to have a knowledge of the fundamental principles of treatment. In order to have such knowledge, it is necessary to understand what is involved.

A patient suspected of injury to the skeletal system should be carefully and systematically examined. His head, neck, back, abdomen, and extremities should be gently palpated (felt), and any tenderness, deformity, abrasions, lacerations, swelling, bleeding, crepitus, localized heat or cold, color changes, and associated injuries noted. If the patient is conscious, he can be of great assistance in revealing his condition to the examiner. There is a vital relationship between first aid and ultimate results in injuries to muscles, joints, and bones, and all divers should learn proper immediate care so that complete functional recovery can follow.

CONTUSIONS

A contusion, or bruise, results from the crushing or tearing of muscle tissue or tendon. The overlying skin may be lacerated or abraded, but is generally intact. There is swelling, tenderness, and discoloration due to the rupture of blood vessels in the vicinity of the injury. The color of the overlying skin ranges from red through blue or black, and finally changes to yellow or green progressively over several days. These color changes are due to the breakdown of blood pigments which are gradually reabsorbed. A rapidly forming swelling indicates that more and larger blood vessels have been ruptured. A black eye is a common example of a contusion.

Treatment

Treatment of contusion is generally unnecessary. If it is severe enough to produce a mild shocklike state, associated injuries including fracture should be suspected. Contusion may be attended with rapid swelling which is an indication of subcutaneous hemorrhage. In an extremity, the hemorrhage may be controlled by a pressure bandage which should be started below the injury in the region of the hand or foot and carried upward toward the contused area. It should always be applied over a wide enough area to avert a tourniquet effect. The part should be elevated. Circulation checks should be performed periodically to be sure arterial circulation is not constricted. If pulses are difficult to palpate, the nail beds will serve as alternate indicators of adequate circulation. In the first few hours after injury, cold applications may help slow down the subcutaneous hemorrhage. After several days, mild heat may help hasten the absorption of old blood. Extremes of heat or cold are to be avoided, however, because of possible damage to skin and underlying tissues.

A medical officer should be consulted as soon as possible to determine the presence of other, possibly more important injuries to head, chest, or abdomen, and particularly when shock is present or develops.

STRAINS

A strain results when muscle or tendon is stretched to the point of partial or even complete rupture. In severe strain, hemorrhage may be associated due to accompanying blood-vessel rupture. Usually strain results from a violent exertion or a sudden, unexpected movement. The patient complains of pain in the affected muscle with stiffness and lameness. There may be some localized swelling over the area, and if there is complete rupture of a muscle or tendon he may lose power of the affected muscle. A distinct gap may be felt at the site of rupture and there may be swelling above where the muscle has retracted. Such ruptures are seen in the biceps of the arm and the heel cord at the back of the ankle.

Treatment

Treatment of minor strains consists of supportive adhesive strapping or bandaging combined with rest. In the first 12 to 24 hours when bleeding within the injured muscle may be occurring, the application of cold is desirable. Although there is little scientific data to support the theory that cold applications help control or decrease hemorrhage, practical experience has shown that swelling and other complications are diminished when this method of treatment is followed. After 1 to 2 days, *mild* heat is helpful.

In severe pain, particularly with complete rupture of a muscle or tendon, the part should be immobilized by splinting or bandaging so that the affected muscle is in a relaxed position. This permits the torn fibers to approximate (approach) each other, aiding in healing.

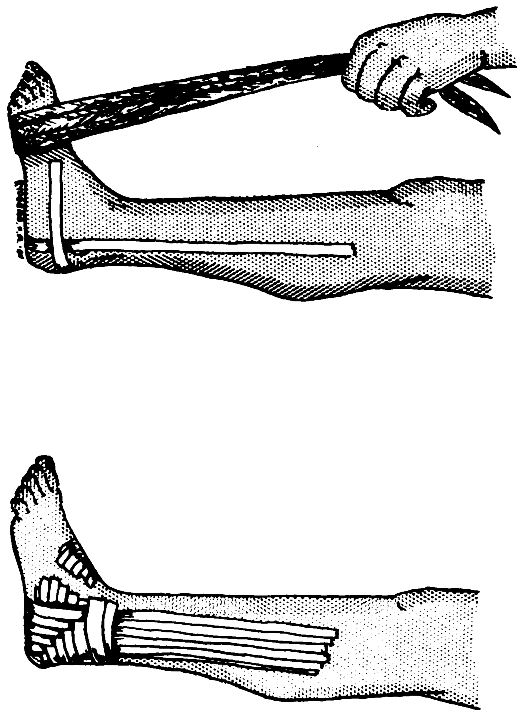


FIGURE A–26.—Method of strapping ankle.

SPRAINS

A sprain is an injury about a joint caused by wrenching or twisting of its ligaments and adjacent soft parts. There is often momentary dislocation and automatic reduction of the joint, at which time injury to the joint cartilage itself may occur. This is especially true in injuries about the knee or ankle. Injuries of the knee may be complicated by tears of the semilunar cartilage. Sprains are usually severe enough to be associated with hemorrhage into joints, and may be quite painful. Fractures may also occur with a sprain, and this possibility should be kept in mind.

Treatment

The treatment of sprains, in all but the most minor cases, should be made by a medical officer. If such care cannot be provided immediately, the joint should be elevated and cold applied in the form of moist packs or an icebag for about an hour, to allay subcutaneous hemorrhage. Then a snug, smooth bandage should be applied to assist in keeping the joint at rest so that the torn ligaments may have an opportunity to heal. A cotton-elastic bandage makes a comfortable, easily applied splint which is compressive. It does have a potential danger, however, in that it may be applied too tightly or may become too tight later from swelling. Or, a roller cotton bandage (muslin) can be quite comfortable. Both types should lie smoothly against the skin and be applied over a wide enough area to prevent a tourniquet effect. The circulation should be checked after such bandaging using as guides either the capillary flush of the nail beds, or the arterial pulsations beyond the bandage. Venous obstruction may lead to swelling of the hand or foot beyond the injured area, and may be caused by continued soft-tissue bleeding as well as by the bandage being too tightly applied.

Minor ankle sprains may be treated by application of a basketweave adhesive strapping if associated fracture has been ruled out (fig. A–26). (Care must be taken in application. Strapping must never completely encircle the limb.) Fracture is suggested by obvious tenderness over the malleoli of the ankle, crepitus, or deformity not due to swelling alone. Weight bearing should not be permitted until the condition has been evaluated by a medical officer.

DISLOCATIONS

A dislocation of a joint occurs when the bones which form the joint slip away from each other beyond their normal relationships. Usually there is locking of the bones in the new position, with accompanying pain and muscle spasm. Tears of the supporting ligaments and sometimes of the surrounding muscle attachments occur unless the dislocation is a recurrent one or unless there is a developmental laxity of the supporting ligamentous structures. The first time the dislocation occurs there may be rupture of blood vessels, and bleeding into the joint itself.

A dislocation may be complicated by a fracture. A sprain may have a momentary dislocation which reduces itself, but a dislocation usually results in the locking of the bones in the new position and deformity is immediately obvious. When a fracture complicates a dislocation, there may be unnatural movement which occurs between the fractured ends of the bone rather than at the joint itself, in which case there may be grating (crepitus). In dislocations one of the bones involved may be easily palpated in an unusual position.

Dislocations or suspected dislocations should have X-rays taken whenever possible. Early reduction of a dislocation is highly desirable in the effort to restore normal function of the joint. Under special conditions when adequate medical aid is not at hand, nor will be at hand within several hours, an attempt to effect reduction of the dislocation should be made because sustained stretch on a dislocated joint capsule may shut off the blood supply carried by it to the adjacent bones. After reduction has been effected, splinting of the joint in a position of function is strongly advised. This favors soft-tissue, especially ligamentous, healing.

Treatment

The treatment of dislocations consists in restoring the bones to their normal position, followed by the splinting of the joint so as to prevent redislocation and to promote healing of the torn ligaments. Some dislocations will slip back into place easily, but others will reduce only with general anesthesia, and great care must be used in assessing each situation. Reduction must be gentle to prevent additional damage to soft tissues, blood vessels, nerves, or even bone. If the circulation and nerve supply to a part are good, and if medical facilities can be reached within 8 hours, then the part should be splinted and the patient should be sent on to the care of a physician. If the circulation is in apparent jeopardy, with or without a nerve injury, and if medical aid cannot be obtained for some time, then reduction should be attempted by a diver as follows: With the aid of an assistant who pulls steadily in the opposite direction, the diver should grasp just below the dislocated joint and apply gentle traction for several minutes to help overcome the protective muscle spasm. This traction in itself may reduce the dislocation, but sometimes after prolonged traction a gentle motion at the joint is required to move an interposed soft part out of the way. After two or three attempts to reduce the dislocation have failed, then the dislocated joint should be splinted and the victim evacuated as rapidly as possible. Early evacuation is vital when there seems to be circulatory damage.

Dislocation of the Jaw

In this condition the patient cannot speak or close his jaws. The dislocation is due generally

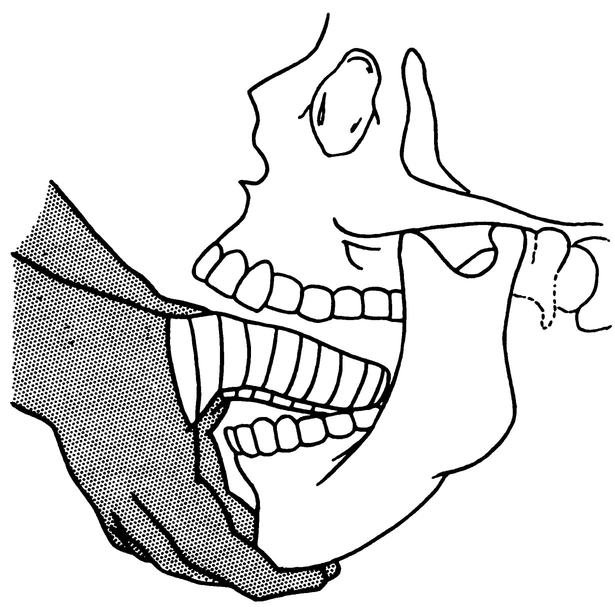


FIGURE A–27.—Reduction of dislocated jaw.

to a blow on the open mouth or to yawning or laughing.

Treatment

The dislocated jaw usually is fairly easily reduced, but the operator must wrap his thumbs well to protect them from being bitten as the jaw snaps back into place. To reduce, place the well-wrapped thumbs just behind the last molars, then press downward with a gentle, firm push. At the same time lift the chin upward with the fingers (fig. A–27). The jaw usually snaps at once into place. After reduction the patient should avoid opening his mouth any oftener or wider than necessary for several days.

Dislocation of the Finger

The finger joints are vulnerable to injury, and are apt to stiffen after injury if not adequately treated. Every finger injury must be regarded with the greatest respect.

Treatment

A dislocated finger may be reduced with a firm, steady pull on the dislocated end, at the same time bending the finger backward if the dislocation is forward or forward if the dislocation is backward. If the dislocation cannot be corrected easily, it is probable that a tendon is interposed between the bones, or that there is a rent in the capsule which has contracted about the ends of the bone. These situations call for skilled surgical management, and the patient should be evacuated to a medical facility as soon as possible. Splinting of the finger should be carried out with the joints slightly flexed—a position best envisioned by forming the letter "O" with thumb and forefinger. This position can be maintained by using a padded aluminum splint, or a roller gauze bandage over a throat stick (fig. A–28); in both methods, adhesive strips are used to secure the splint to the fingers.

Dislocation of the Shoulder

When the shoulder is dislocated, it may be in one of several positions (fig. A–29). In the more common type of dislocation, the arm is rigid, and the elbow is held away from the body at a distance of 3 or 4 inches. The bony tip of the

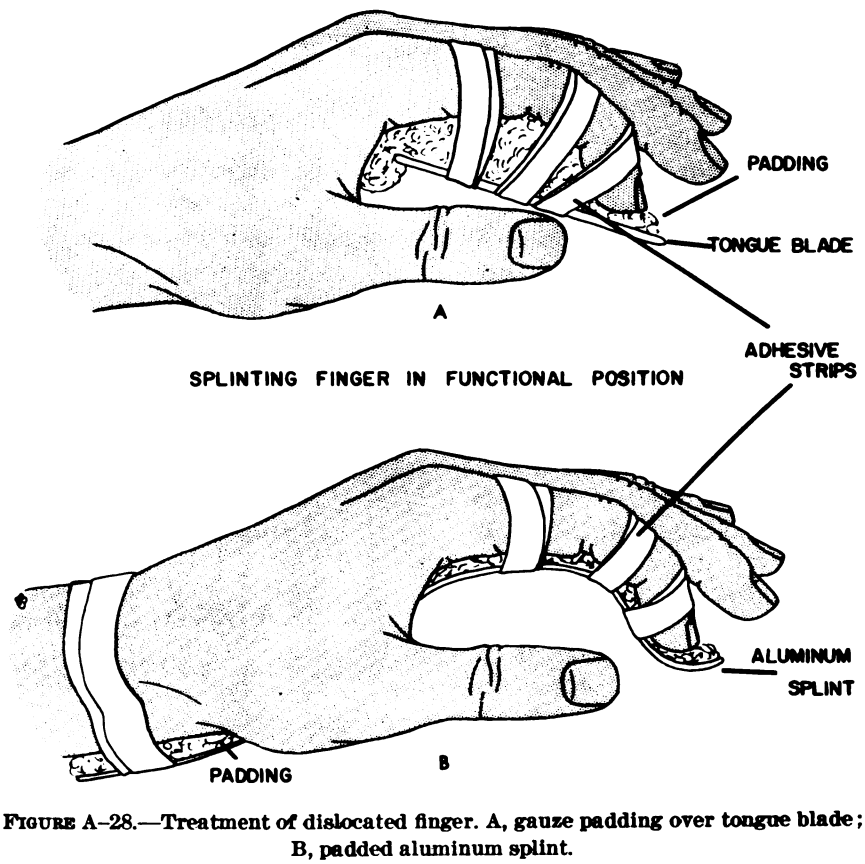


Figure A–28.—Treatment of dislocated finger. A, gauze padding over tongue blade; B, padded aluminum splint.

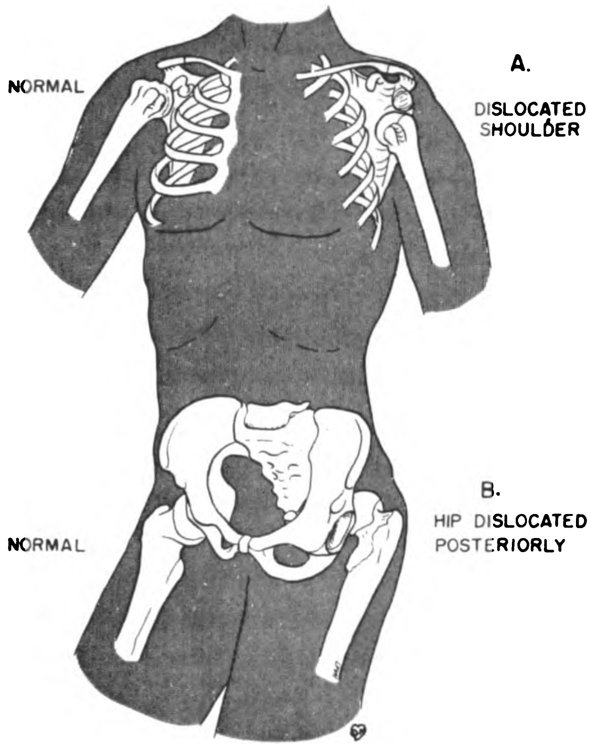


FIGURE A–29.—A, dislocation of shoulder; B, dislocation of hip.

shoulder is more prominent than on the normal side. In all dislocations, motion is markedly limited and attempts at motion are painful.

Early reduction of such dislocations is far easier than delayed reduction. If professional medical help will not be available within an 8-hour period, it is reasonable for the diver to attempt reduction.

Treatment

The patient should be put in a supine position. The diver then should take off one shoe and insert the heel of his foot under the armpit of the dislocated side at the same time applying steady traction on the affected arm by grasping the wrist. The pull should be started gently and increased very gradually for the patient may have considerable muscle spasm which is best overcome by a gentle steady pull. Beware of sudden jerks as they are apt to cause painful muscle spasms, or too much tension as soft-tissue injury may be produced.

The arm should be pulled in the same line as the arm lies. After several minutes of steady pull, flex the elbow slightly and grasp the arm above the elbow and apply traction. As traction is applied, gently rotate into external or outward position. This may cause the humeral head to slip back into its normal position. Then carry the forearm across the chest; the arm is thus internally rotated with the elbow and is now able to rest against the side of the body. A sling and swathe will afford sufficient immobilization.

If reduction is unsuccessful after a few attempts, it is wiser not to persist in attempting reduction, for nerve or artery damage may result. The patient should have his affected arm supported by a sling and swathe and be transported to a hospital facility.

Dislocation of the Hip

This major injury is mentioned specifically because it is occurring with increased frequency in this era of high-speed automobiles. Most often the hip is dislocated backward (fig. A–29); this is caused by the knee striking the dashboard, and the force thus generated is transmitted along the femur to the flexed hip. In such a patient the knee is turned inward and the thigh is fixed toward the midline. Fractures of the rim of the socket of the hip joint may be associated with the dislocation. Attempts to move the hip are painful. Dislocations where the head of the femur leaves the hip socket toward the front are less common, but are associated with the knee being rotated outward and also fixed so that the casualty's knee cannot be brought to the midline.

Treatment

First aid consists of transporting the patient to a medical facility at the first opportunity and making him as comfortable as possible by carrying him on a stretcher, using pillows to support his knee and leg so that movement will be minimized. Only under circumstances where the patient cannot be brought to a physician's care within 8 hours should an attempt to reduce the dislocation be made. Reduction is easiest if attempted soon after dislocation because with each passing hour, protective muscle spasm of large muscles about the hip increases, and eventually reduction becomes possible only under anesthesia.

Under the limited circumstances mentioned above, an attempt at reduction may be made by applying a gentle but firm pull on the leg on the

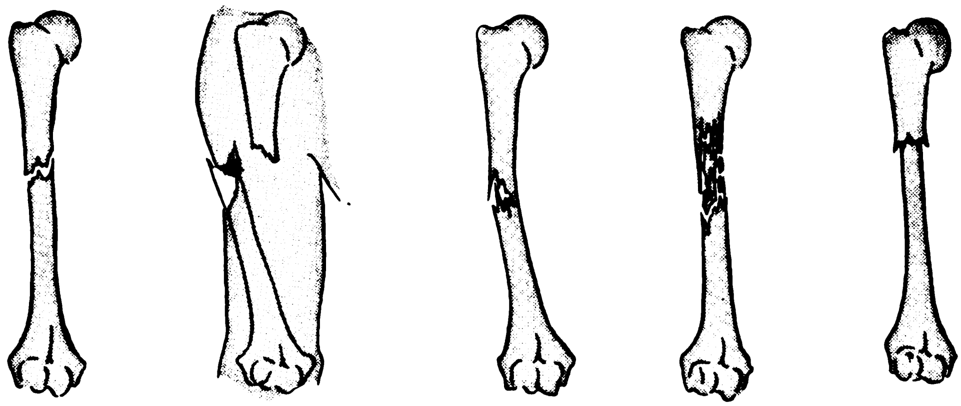


FIGURE A–30.—Types of fractures.

side of the dislocated hip. The patient should be lying on his back, either on the floor or on a table. An assistant should hold the pelvis down while traction is applied. The hip should slowly be flexed while the traction is increased, and a steady pull along the axis of the femur should continue for at least 5 minutes. As the hip is flexed toward a right angle, reduction usually is manifested by a muffled "klunk." If reduction is not effected by this maneuver, no further attempt should be made.

FRACTURES

A fracture is a broken bone, but the break need not be complete to be so identified (see fig. A–30). A broken bone should not be regarded as an isolated phenomenon. One or more of the following conditions may accompany: torn vessels, hemorrhage, bruised muscles, damaged nerves, and swelling.

Fractures may be classified as—

1. *Closed fracture* (simple fracture).—The bone is broken but the skin is unbroken.
2. *Open fracture* (compound fracture).—There is an open wound so that the broken bone communicates with the outside of the skin.
3. *Greenstick fracture.*—The bone shaft is bent and cracked, but is not completely broken through.
4. *Comminuted fracture.*—The bone is crushed, splintered, or broken into a number of fragments. The overlaying skin may be either closed or open.
5. *Impacted fracture.*—One fragment of bone is forcibly driven into another and remains more or less fixed in that position.

All injuries produced by force should be examined with fracture in mind. Any deformity, crepitus, local tenderness, swelling, pain on movement, even a statement from the casualty that he feels he has a broken bone, should call for extreme care in examination and transportation. Open fractures are particularly troublesome because of the serious threat infection, and movement of bone fragments in closed fractures may cut and tear soft tissues, causing hemorrhage and shock. When in doubt as to whether or not a bone is broken, treat the casualty as a fracture patient.

Skull Fracture

Whether or not the skull is fractured (fig. A–31) is less important than whether there has been an injury to the brain. First-aid efforts

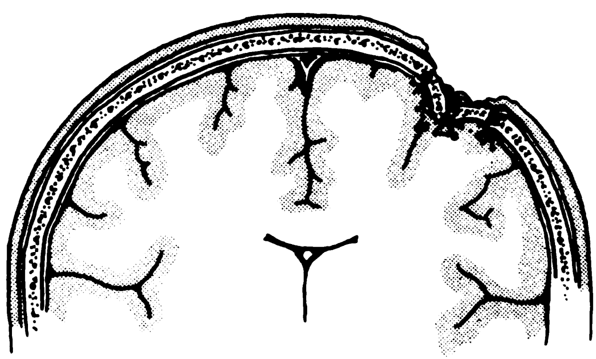


FIGURE A–31.—Fracture of the skull.

should be directed, therefore, toward determining the extent of the brain injury and management of the casualty so that he can survive the initial period to receive skilled care by a neurosurgeon later.

Treatment

Under "Craniocerebral Injuries," first-aid care has been delineated for those with injuries to scalp and brain. The role of a diver in caring for the fracture site or open skull-bone wound is limited. First, the wound should be protected with sterile gauze and the area surrounding the defect cleansed. It is advisable to shave the hair which is usually matted with blood and dirt. Then remove any gross foreign material. Large penetrating bodies must be left alone because of the danger of hemorrhage. No attempt should ever be made to probe the wound for skull fragments or to retrieve foreign bodies. A liberal dressing should be applied and secured for transporting the casualty to professional care. Care of the casualty, attitude of bodily placement, and so forth, are set forth in "Craniocerebral Injuries."

Fracture of the Nose

There is usually considerable deformity (the bridge of the nose being depressed and pushed to one side). Crepitus (vibration caused by one bone fragment rubbing on another) can usually be felt. A considerable nosebleed may be present (fig. A–32).

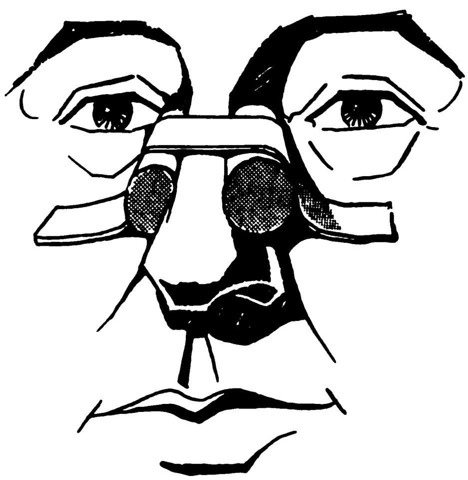


FIGURE A–32.—Fracture of the nose.

Treatment

Treatment should include a gentle attempt to return the bones to their normal position (see "Nose Injuries" for procedure). A splint to hold the bones in their reduced position may be made by using two very small rolls of narrow bandage on either side of the nose; these are held in place with short strips of adhesive tape.

Fracture of the Jaw

A broken jaw is usually readily recognized by obvious deformity following a blow to the jaw (fig. A–33). The patient may have difficulty in talking, eating or swallowing, with pain on moving the jaw. In undisplaced jaw fractures the teeth should be in perfect alinement, whereas in minor displacements of the bone fragments their alinement is imperfect. Some bleeding about the gum margins near the site of fracture may be present. Considerable swelling may develop slowly.

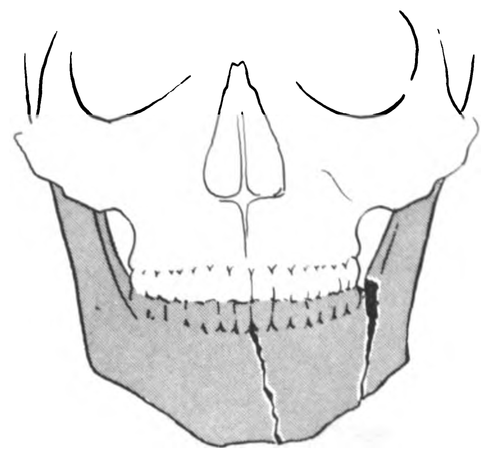


FIGURE A–33.—Fracture of the jaw.

Treatment

Treatment should include—

1. Application of a four-tail or Barton bandage to hold jaw in place and to prevent excessive movement (fig. A–34).
2. Icebags to relieve pain and swelling.
3. Aspirin for pain.
4. A liquid diet only.
5. Refer the patient to a dental or medical officer as soon as possible.

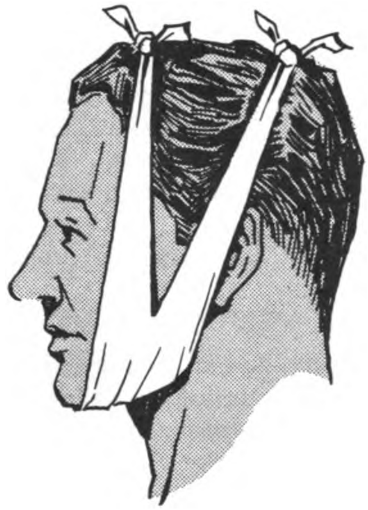


FIGURE A–34.—Bandage for a fractured jaw.

Fracture of the Neck

All fractures of the neck are serious and all require prompt diagnosis and treatment. Because of the spinal cord and the nerves which leave the spinal cord at segmental levels, any injury of the neck should be handled with caution so as to prevent rotation, side bending, or flexing and extending the neck (see "Maxillofacial and Neck Injuries").

Treatment

First-aid treatment consists of immobilizing the neck so that neither flexion nor extension results, and the neck stays in neutral position (fig. A–35). A firm stretcher is required for transporting the casualty; a canvas, collapsible-type litter must be firmed up by placing boards,

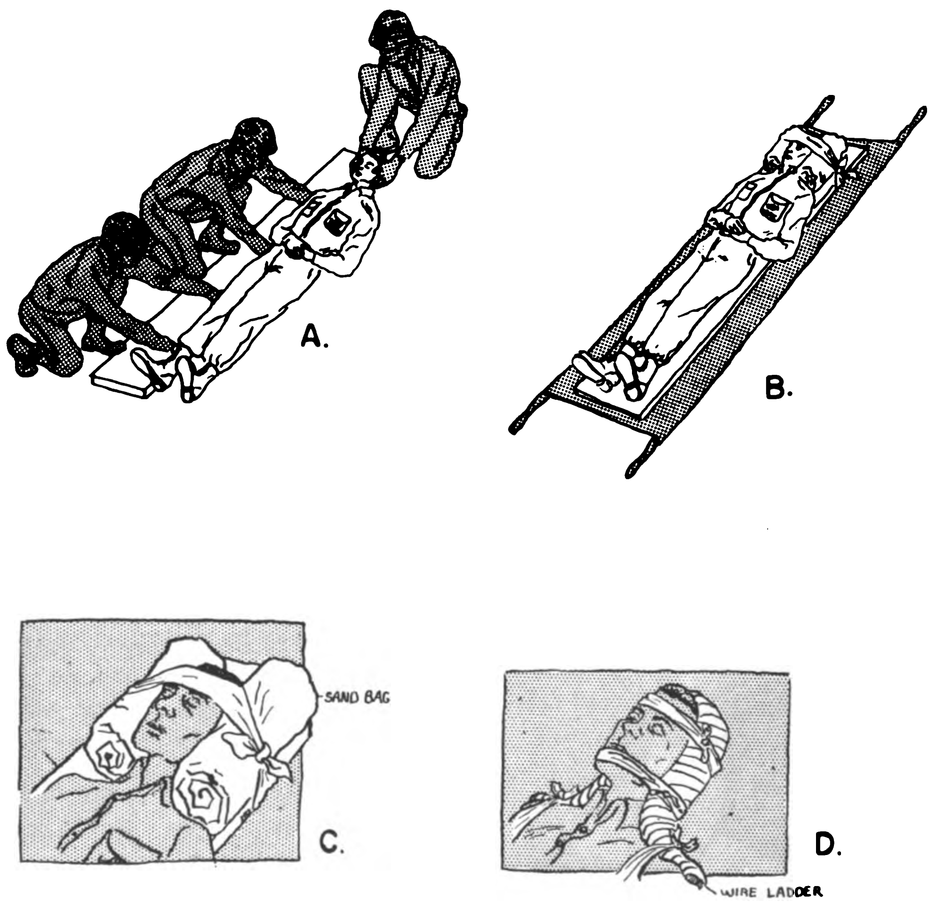


FIGURE A–35.—Transportation of casualty with neck injury. A, placing casualty on litter; B, casualty on litter with sandbags immobilizing neck; C, detail of sandbag placement; D, details of wire ladder for immobilization.

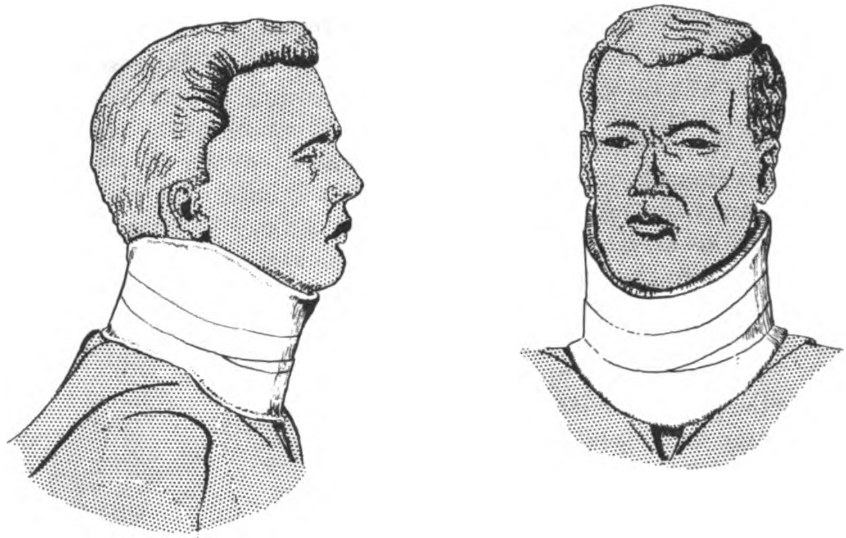


FIGURE A–36.—Immobilization for fracture of the neck.

shutter, et cetera, in its center. Three men should lift the patient onto the litter in order to maintain him in the neutral position.

There may be occasions when a wraparound collar will be necessary to immobilize the neck (fig. A–36). Maintenance of the neutral position during application is difficult and requires the aid of others to keep the neck from rolling. Sandbags, or any improvised staying support such as padded bricks, should be used on either side of the head during transportation to stabilize the neck when a wraparound collar is not available. The casualty should be kept lying on his back unless he is unconscious, in which case he must be protected against choking on his own secretions by lying face down with his head turned to the side. His chin should be gently held forward, but not with so much force as to extend the head and neck.

Fracture of the Clavicle

The shoulder on the side with the broken clavicle (collarbone) droops somewhat inward and forward. Because the clavicle lies immediately beneath the skin, it is readily palpable. As in other fractures, pain and local tenderness occur at the fracture site. Although a rare complication, fragments of bone can injure the major blood vessels to the arm which pass in close approximation beneath the clavicle. For this reason fractures of the clavicle should be splinted.

Treatment

Treatment consists of using a figure-of-eight bandage to hold the shoulders up and back, thereby immobilizing the fragments of bone (fig. A–37). The bandage should be firm and padding should be applied against the axilla to prevent the bandage from cutting. To apply the bandage, hold the end of a 3-inch bandage on the outside of the shoulder and carry the roller diagonally downward across the shoulder blades, around the axilla (armpits), and over the shoulder of the opposite side. Continue downward across the shoulder blades to the axilla and up over the shoulder to the starting point. Repeat the procedure for three additional turns, overlapping the preceding turn by one-

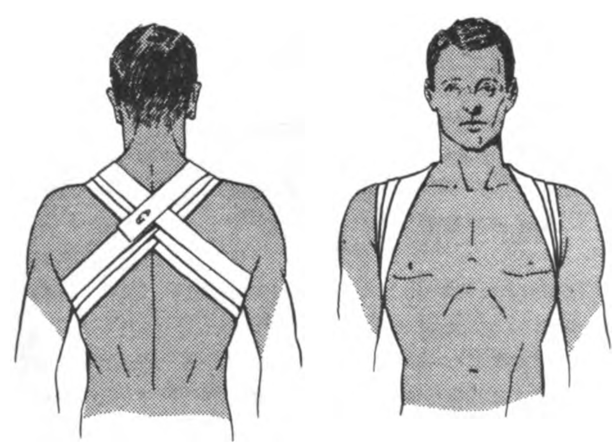


FIGURE A–37.—Bandage for fractured clavicle.

third its width. Secure the ends with adhesive strips or with a safety pin. Transport the patient to a medical officer as soon as possible.

Fracture of the Humerus

The humerus extends from shoulder to elbow, and around its shaft runs the radial nerve in close proximity. At the lower end, the median and ulnar nerves lie close to the bone, as does the brachial artery. At these sites, therefore, nerve and artery injury may complicate fractures (fig. A–38). Fractures of the upper end may be suspected by the pain and swelling, and, if impacted, no crepitus or unusual motion at the fracture site will be noticed. Fractures of the shaft are more often complete, and crepitus and deformity are more likely to accompany the painful swelling. Fractures which involve the lower end may also involve the joint so that the patient may have considerable pain on the slightest attempt at moving the elbow joint. Because of the dangers of nerve and artery injury, it is important that immobilization be made prior to transporting the patient to a medical officer.

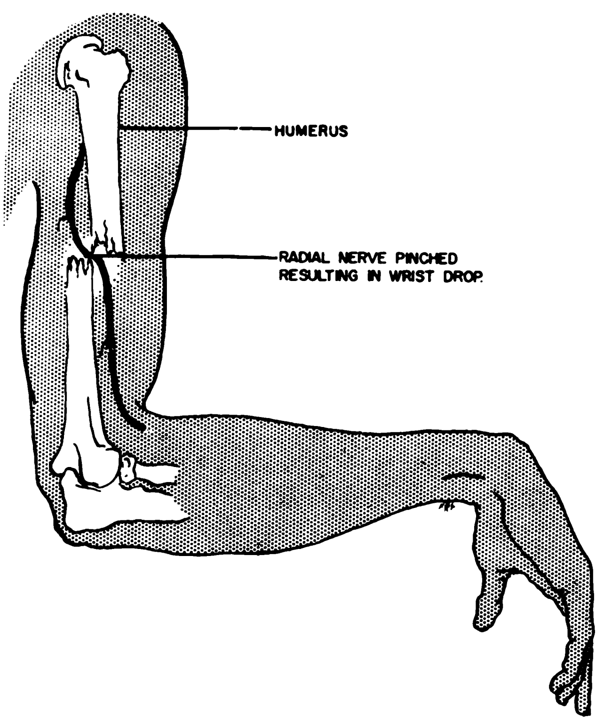


FIGURE A–38.—Nerve injury with wrist drop in fracture of humerus.

Treatment

Treatment of fractures of the humerus varies according to location as follows:

1. Fractures of the upper end of the humerus commonly involve the surgical neck, and may be relatively safely and easily immobilized with a sling and swathe after applying a folded towel in the armpit. The sling should permit the weight of the arm to hang just a bit, setting the sling in its fixed position so that it supports the wrist and not the elbow (fig. A–39).

FIGURE A–39.—Treatment of a fractured humerus.

2. Fractures involving the middle portion should be immobilized with padded coaptation splints placed about the arm and secured with a bandage. The wrist and forearm should be supported by a sling if the elbow flexes to nearly normal. The coaptation splints should not extend so high in the axilla as to compress vessels or nerves, but may run up higher on the outer aspect of the arm. If the fracture is such that the elbow cannot be flexed, long coaptation splints may be applied with the elbow extended (out straight). These should be padded (fig. A–40). Constrictive pressure from a circular bandage or adhesive strips should be avoided.

3. Fractures involving the lower portion may include the elbow joint. If the elbow can be flexed, a sling and swathe may be sufficient for immobilization. If the elbow is extended and cannot be flexed comfortably, long padded coaptation splints may be useful for comfort.

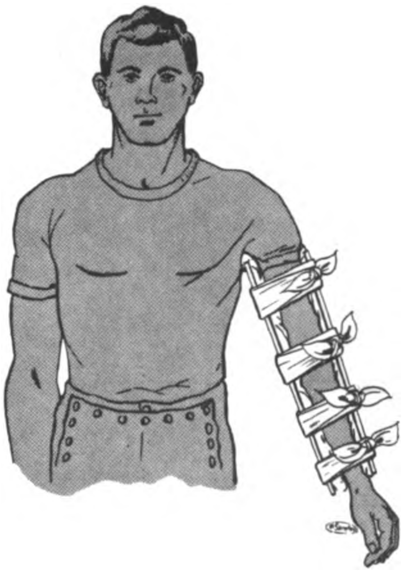


FIGURE A–40.—Splinting with elbow in extension for some fractures about the elbow.

Fractures of the Bones of the Forearm

When both bones of the forearms are fractured, all the usual signs of a fracture are present. When only one of the bones is broken, the other acts as a splint and usually little deformity is present, but always there is an inability to use the forearm. On examination, tenderness and a false point of motion can be discovered at the site of injury. A fracture of the lower radius may occur alone or with a small chip off the ulnar. This is the most commonly seen fracture of the wrist and the deformity is termed a silver-fork deformity. Such a fracture is universally known as a Colles' fracture (fig. A–41). In this fracture the bones are usually impacted and no crepitus is present.

Treatment

Treatment of fractures of the forearm includes immobilization. This can be done with padded basswood splints or even splints made

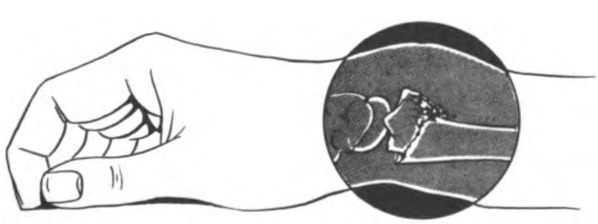


FIGURE A–41.—Colles' fracture.

of folded newspapers. They should be applied with one in front and one on the back of the forearm. The elbow may be kept immobile with a sling. More severe fractures may be complicated by injuries of the blood or nerve supply to the hand. Examine the casualty for the presence of nail-bed pulsations and sensations as well as the ability to move the fingers. The casualty who has artery or nerve injury has an emergency situation which calls for the earliest possible treatment by a medical officer.

Fractures of the Wrist and Hand

Generally wrist fractures include the Colles' fracture described above. However, the small bones of the carpus are also part of the wrist. These small bones may be fractured or even dislocated by falls on the outstretched hand. They are generally painful, locally tender, and should be suspected in any sprain of the wrist.

Treatment

First-aid treatment consists of splinting the wrist with a padded basswood splint on the flexor surface extending from the elbow to below the fingertips (fig. A–42). Because X-rays are

FIGURE A–42.—Splinting of wrist and hand injury.

necessary for complete diagnosis, the patient should be evacuated to appropriate medical facilities.

Fractures of the metacarpal bones are usually caused by direct blows. Two such commonly occurring injuries result from fistfighting: fractures at the base of the thumb and of the neck of the fifth metacarpal bone. A short basswood splint and a fluff of gauze or absorbent cotton to maintain the hand in a cupped position are desirable.

Fractures of the fingers may be closed or open. Both types demand early attention by a medical officer. Such fractures may be splinted over a tongue blade for transportation purposes, but with rare exceptions fractures of the fingers should be in the position of flexion. Because of the rapidity with which stiffness may develop, casualties with injuries involving wrist and hand should be given priority status for evacuation to professional care.

Fracture of the Ribs

Those with fracture of the ribs complain of localized pain on breathing, coughing, or sneezing, and have tenderness at the site of the fracture. Fragments of bone may puncture the lungs, either at the time of injury or subsequent to injury. When this happens, the patient may spit up blood. Air from the punctured lung may escape into the pleural space or even into the soft tissues of the chest wall. The examiner should systematically palpate along each rib from front to back to note the site of tenderness or of crepitus. By listening with an ear to the chest one may actually hear the grating or crepitus as the patient breathes.

Treatment

Treatment of rib fractures calls for adhesive strapping of the involved side of the chest, since it is nearly impossible to immobilize just the one or two ribs which are usually fractured. First, the skin is cleaned and dried. Compound tincture of benzoin is next applied to the skin of the side involved. Then, strips of 2-inch adhesive tape are applied from front to back, starting low on the chest wall at the midline. The patient should be asked to take a deep breath and exhale. While he holds his breath in exhalation, the tape should be applied in the same axis that the ribs run toward the back starting across the midline in the front and continuing across the midline in back (see fig. A-43). The strip below should overlap the one above by about one-third of its width.

When adhesive tape is not available, muslin may be used or a cravat bandage, but these do not immobilize the area as satisfactorily as the adhesive tape.

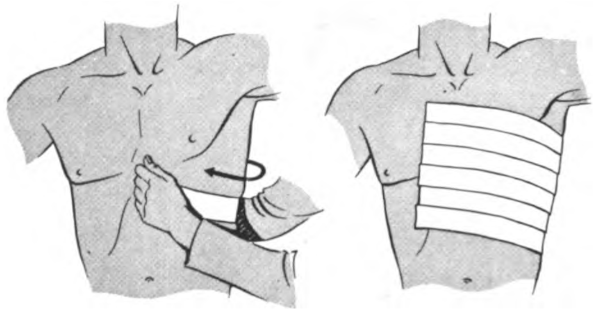


FIGURE A-43.—Strapping of a fractured rib.

If a lung has been punctured and the casualty is spitting up blood, he should be kept quietly in bed until he can be transported to professional care. This is a priority-evacuation type of injury.

Fracture of the Spine

In fractures of the spine, the possibility of injury to the spinal cord as a complicating factor should be borne in mind (fig. A-44), for

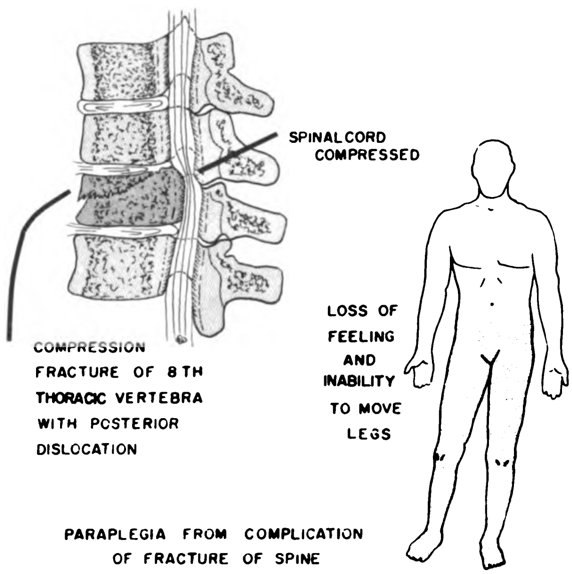


FIGURE A-44.—Complications of fracture of the spine.

transporting a patient with fracture of the spine may result in injury to the cord if complete immobilization is not accomplished. (See "Spine and Spinal Cord Injuries" for diagnostic aids.)

Treatment

Though there are diagnostic aids to determine the area of fracture, it is impossible to pinpoint the area without X-rays. The first problem, then, is to move the casualty to a medical facility where such equipment is available and to accomplish the move without inflicting further injury. The casualty should be transported by stretcher (which has been made firm with the addition of boards, or any similar, improvised material), preferably lying on his back so that his spine is neither hyperflexed nor hyperextended (fig. A–45). If the casualty is found lying face down,

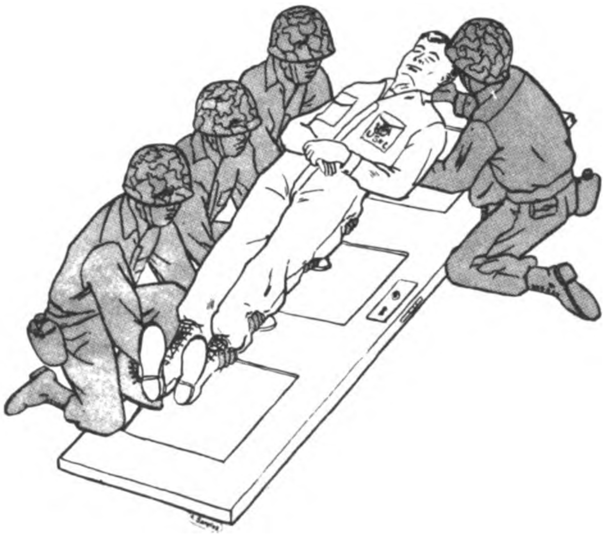


FIGURE A–45.—Transportation of casualty with spinal injury.

he should be rolled as a unit to avoid twisting the spine, and lifted by several men to permit the stretcher to be placed under him. If the patient is unconscious he must be transported in in a prone position (see "Fracture of the Neck," this section).

CAUTION

Never permit a casualty with involvement of the spine or neck to sit up.

Fracture of the Pelvis

Fractures of the pelvis may range in severity from fractures without bone displacement to those with *marked* displacement. Of the viscera which the pelvis encloses, the bladder is the most vulnerable to injury by displaced bone fragments. If the fracture is severe, the casualty may be in great pain, unable to sit or stand, and may be unable to move his legs because of pain and muscle spasm. A patient with a pelvic fracture complicated by perforation of the bladder or the urethra will pass gross blood from his urethra on urinating or even without urinating (fig. A–46).

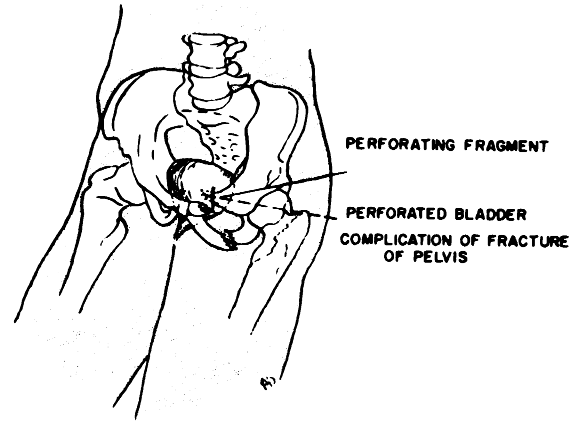


FIGURE A–46.—Pelvic fracture.

Treatment

In first-aid treatment of pelvic fractures, utmost gentleness and care in examining and transporting the casualty are called for. The casualty should not be tested for crepitus, lest bone fragments be displaced. He should be moved only on a stretcher, or other firm surface such as a door or board. The knees and ankles should be bandaged together, with a pad placed between bony prominences (the patient may be more comfortable with his knees partially bent, with a pillow or soft roll under his knees), as shown in figure A–47. The wrapping of the pelvis with a circular bandage which incorporates two pillows may make the patient more comfortable, but this must be done without rolling the patient. It is of the utmost importance to get the casualty to a medical facility for definitive treatment, and this is especially important if he has a ruptured bladder. Priority scheduling for evacuation should be sought if professional care and X-ray facilities are not immediately available.

FIGURE A–47.—Immobilization for transportation of fractured pelvis.

Fracture of the Hip

Every individual who complains of pain in the hip following injury or after a fall should be considered to have a fracture until it can be proved otherwise. In fracture, there is pain on motion; and because of the pain, the casualty cannot move his leg. Generally, the affected leg rolls outward.

Treatment

The casualty should not be permitted to walk or to sit up. Transportation should be by stretcher. If a Thomas leg splint (see under "Fracture of the Femur," below) is available it should be applied. If no such splint is at hand, a splint which runs from the foot to above the hip joint should be improvised (see fig. A–48). If no material for a splint can be found,

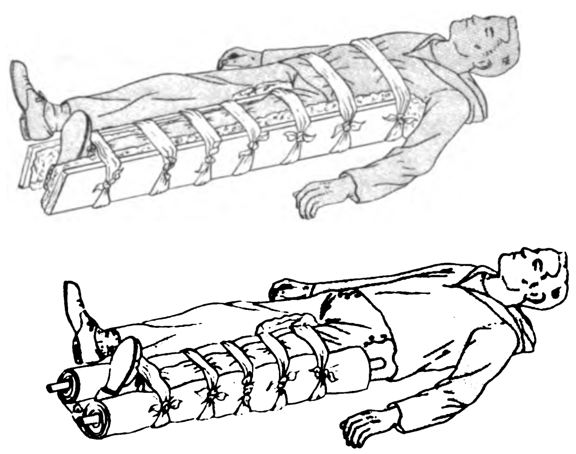


FIGURE A–48.—Immobilization for transportation of fractured femur.

as a last resort the normal leg can be used and the affected leg bound to it with pads between the bony prominences at knees and ankles.

It should be pointed out that some hip fractures involve a large surface of bone with severe pain accompanying, and such patients are very susceptible to shock. In all instances of fracture of the hip or leg bones, splinting by some means or another must be accomplished before transporting the casualty.

Fracture of the Femur

Strictly speaking, the fractured hip involves the head, neck, or trochanteric region of the femur. This section, then, includes only fractures of the shaft and lower end of the femur. The femur is a sturdy, large bone. When fractures occur, there is often considerable bleeding from the bone fragments. This and soft tissue damage may produce shock.

The toes of the leg with the fracture usually point outward, and any attempt to move the limb brings on spasm of the muscles of the thigh causing the patient excruciating pain. The thigh may actually be angulated. There may be actual shortening of the limb on the affected side due to overriding of the bone. The hazards of perforating the skin from within by careless movement of the fragments is always present, as is the damaging of blood vessels or nerves.

Fractures of the lower end of the femur may involve the knee joint in which case great care must be taken to avoid injury to the major vessels and nerves which pass along the back of the knee into the leg.

Treatment

First-aid treatment of fracture of the femur demands the application of a splint immediately, and the casualty must not be moved until this has been done. The most useful splint is the Thomas half-ring splint (fig. A–49). To apply,

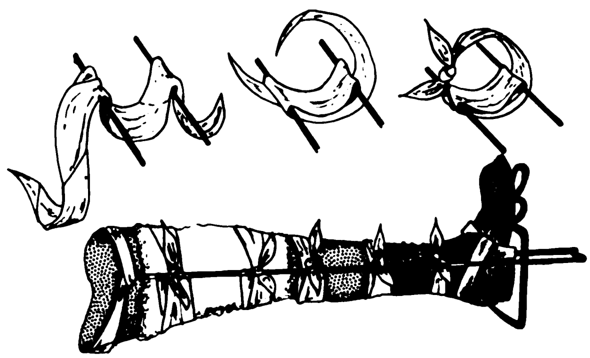


FIGURE A–49.—Thomas half-ring splint.

an assistant should grasp the affected limb at the ankle and exert a steady pull in the longitudinal axis of the leg. The rescuer then places the leg in the splint so that the ring is on the back side of the thigh and the shorter upright of the splint is on the groin side. Next, a cradle is made for the lower limb using two cravat bandages for the thigh, and two more for the leg. These cravats are folded so that they are about

3 inches wide and are then brought around the uprights of the splint, and tied in front of the leg. Finally, a Collins' traction hitch is made about the ankle and tied around the lowermost part of the splint. Using the Spanish-windlass technique, continuous traction may be applied (see fig. A–50).

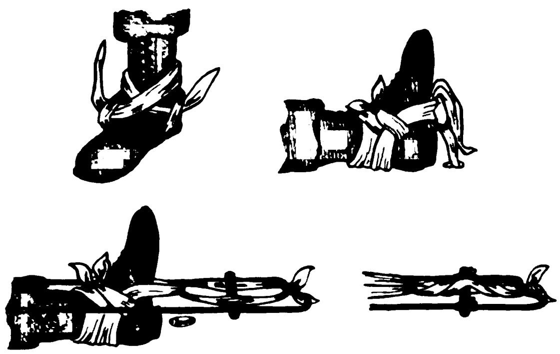


FIGURE A–50.—Detail of tying Spanish windlass for traction.

If Thomas splints are not at hand, long board splints may be used, the outside one extending from the axilla to below the ankle; the other, on the inner portion of the lower limb from the crotch to the bottom of the foot. Five circularly applied cravat bandages should be the minimum for immobilization and should be placed at the ankle, over the knee, just below the hip, around the pelvis, and just below the armpit.

It is especially important to splint fractures of the femur well prior to transporting the patient to a medical facility because of the frequency of shock resulting from inadequate immobilization. The incidence of fat emboli (see "Crush Injuries" for explanation) associated with fractures of the femur will be lessened by splinting as well.

Fracture of the Patella

The patella (kneecap) lies in the substance of the tendon which straightens the knee and is readily palpable. It may be fractured by direct blows or by muscle pull, and when fractured the casualty may be unable to straighten the knee. If there is separation of the fragments, a hollow between these fragments may be easily felt. The patient will have localized pain.

Treatment

First aid for fracture of the patella consists of immobilizing the limb with the knee in a nearly straight position using a padded board on which to rest the leg, and using triangular or muslin bandages to secure the leg to the splint (fig. A–51). Open reduction and fixation of

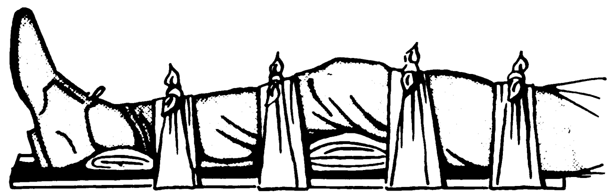


FIGURE A–51.—Immobilization for transportation of fractured patella.

fragments with wire, silk, and the like, are generally required, and early evacuation is recommended. For optimum results, the casualty should receive treatment within 24 hours of injury. Bleeding from the fracture sometimes occurs and this causes rather rapid swelling of the knee joint. Application of a pressure bandage may help allay the swelling and make the casualty more comfortable, but care must be exercised not to create a tourniquet effect.

Fractures of the Bones of the Leg

The leg bones are the tibia and fibula. The tibia, or shinbone, is large, sturdy, and is readily felt in front of the leg throughout its entire length. Because there is so little soft tissue in front of the tibia, fractures may be easily compounded. The fibula, which is smaller, lies on the outside section of the leg, is palpable in its lower end, but is covered with a good volume of muscle in its upper end. When only one bone is fractured, the intact bone acts as a splint, but when both bones are fractured there may be considerable angulation at the fracture site. Local tenderness, crepitus, and swelling will be present in fractures of either bone (fig. A–52).

Generally, fibular fractures occur from a direct blow. At the ankle level, however, the fibula may be fractured by a severe twist. The tibia is vulnerable to fracture from direct blows as well as from twisting forces. Both bones have prominences at the lower end, the so-called anklebones—internal (tibial) and external (fibular)

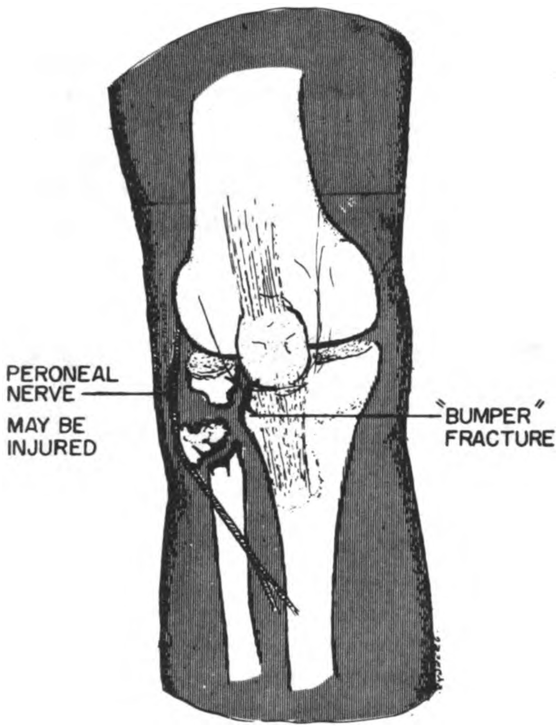


FIGURE A–52.—Bumper fracture. Illustration depicts involvement of upper end of fibula as well as tibia.

malleoli—which contribute to the stability of the ankle joint. The ligaments which bind the fibula to the tibia, and also bind these bones to those of the foot, may be torn in association with the fracture. A dislocation of the foot at the ankle may thus accompany a fracture of the bones of the leg. The diagnosis of such injuries is generally simple to make because of the deformity. Undisplaced fractures can occur, however, and should be strongly considered even when no deformity is present.

Treatment

First aid for fractures of the bones of the leg consists of the application of a Thomas splint or a pillow splint and transporting the patient immediately to the care of a medical officer. An attempt to aline the foot or the lower part of the leg with reference to the upper leg may be made by gentle traction as the pillow splint is being applied (see fig. A–53). (A large, long pillow applied from the underside, brought up around the sides of the extremity, and pinned in several places along the margin of the pillow, makes a satisfactory splint if some rigidity can be pro-

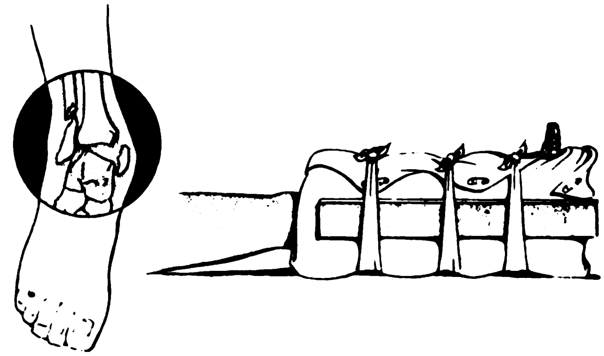


FIGURE A–53.—Pott's fracture and immobilization.

vided in the form of basswood splints or sticks placed along the outside of the pillow and secured with some type of bandage or rope.)

Fractures of the Foot

The foot includes the small bones (tarsal bones) below the ankle joint as well as those of the toes. Generally such fractures are sustained when heavy objects fall directly onto the foot, and fractures of the toes are the most common. The location of the swelling, pain, and tenderness coincides with the bone involved. Less commonly, as in a motor-vehicle accident where the foot may be forced upward or downward, the tarsal bones may be fractured and even dislocated.

Treatment

First aid for severe fractures of the foot involves elevation to allay swelling and to eliminate weight bearing. If some time is going to elapse before the casualty can be treated by a medical officer, the application of cold may help to lessen the degree of swelling. In an undisplaced fracture of a single toe, weight bearing may be permitted if the involved toe is splinted to an adjacent one and a section of the shoe is cut out to allow for swelling. When the fracture is displaced or when several toes are involved, the foot should be elevated and no weight bearing should be permitted.

INJURY TO CARTILAGE

The cartilage which gives a smooth lining to a joint surface is called articular (hyaline) cartilage. It may be injured by a severe shearing action, or by the subjacent bone in association

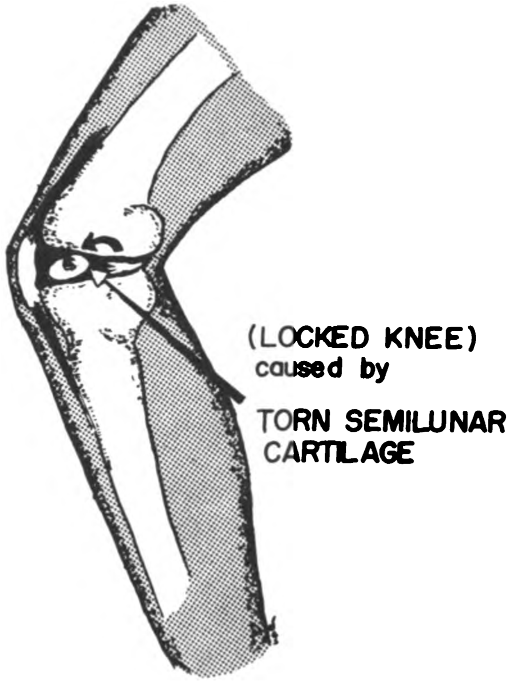


FIGURE A–54.—Torn cartilage in knee joint.

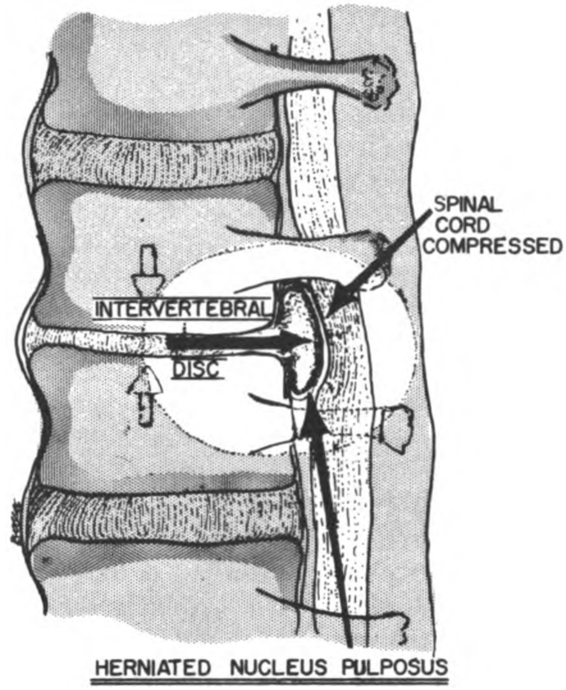


FIGURE A–55.—Injuries to intervertebral disk.

with fractures. There is also a cartilaginous growth plate at either end of long bones in children which may be fractured, and which mimics fractures of bones. Of frequent occurrence are injuries to fibrocartilages which occur mainly at two locations—the knee joint and the spine. The fibrocartilages of the knee joints are called *menisci* or *semilunar cartilages* and are tough structures like gristle. Frequently they are torn by violence as when a block is thrown against a football player or by indirect violence as when the ball carrier twists to turn in another direction with his cleats engaged in the turf (see fig. A–54). In such knee injuries, pain and locking are the principal complaints.

Between the vertebrae are the so-called intervertebral disks which may become displaced when the retaining longitudinal ligaments between the vertebral bodies give way (see fig. A–55). The common site for extrusion of the intervertebral disk is in the lower back (lower lumbar spine); and here the patient has considerable pain, at times greatest in the back, but at other times accentuated in the leg or legs as a result of pressing on one of the roots of the sciatic nerve as it exits from the spine. Rarely does a protrusion of the intervertebral disk occur in the neck, but when it does it may produce severe pain radiating into the arm.

Treatment

First-aid treatment of those with cartilaginous injuries consists of keeping the patient from weight bearing and bringing him under the care of a physician as soon as possible. If he has sustained a tear with displacement of the meniscus of the knee, there may be associated ligamentous tears which would also be aggravated by weight bearing. The patient may be made considerably more comfortable by the application of a wide cotton elastic bandage (Ace bandage).

When the intervertebral disk has been injured, the patient should be kept lying down and transported on a firm stretcher with his hips flexed in a position where he is the most comfortable. Only a medical officer should give permission for the patient to be ambulatory.

A-K. SPLINTS

Splints are used to immobilize a fractured part. There are many types of splits which have been designed for specific purposes and with specific parts of the anatomy in mind as, for example, the molded hand splint. However, because of the limitations imposed by space, only those types (coaptation and traction) usually available will be discussed.

Coaptation splints consist of a series of (but sometimes only two) narrow boards used to envelop a limb, thus fitting or joining together (coapting) the broken bones, and also providing uniform and complete support in the area of the injury. The boards are generally of basswood and are conveniently packaged in varying sizes (fig. A-56); they are held about the limb by means of roller bandages, cravat bandages, or any available material as handkerchiefs, rope, clothing, adhesive tape. When basswood splints are not available, canes, rifles, sticks, stiff wire, or folded blankets may be used to support the broken bones. Coaptation splints have been used for centuries.

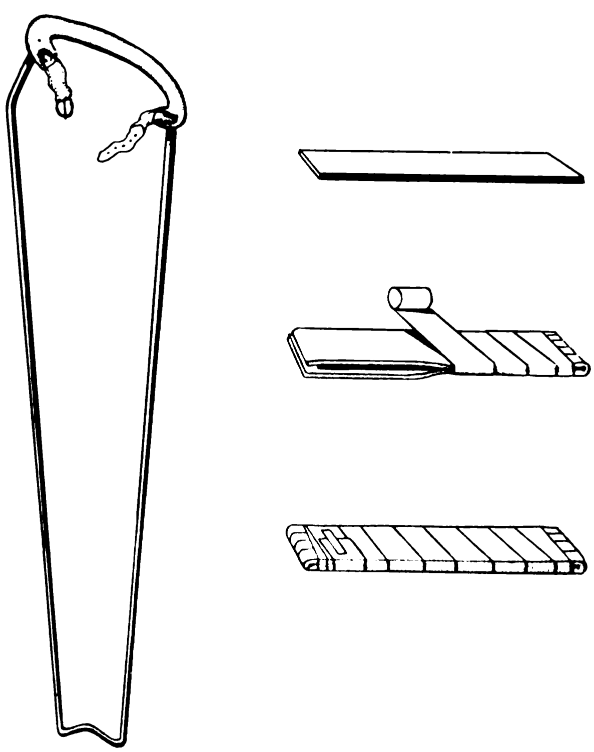


FIGURE A-56.—Thomas half-ring splint and basswood boards for coaptation splint.

Generally, coaptation splints should be long enough to reach the joints above and below the fracture; they should be wide enough to prevent pinching; and they should be padded except, perhaps, when applied over thick clothing. Padding may be of oakum, cotton, clean rags, grass, moss, or pieces of blankets or clothing. An assistant should be sought to support the limb during application to prevent excessive motion at the fracture site.

Traction splints, of which the Thomas half-ring splint for the leg is a well-known example, serve to immobilize the limb, resting it in a trough. Most importantly, however, they have a feature that provides for a pulling action (traction) and this prevents overriding of bone fragments. A Spanish windlass permits application of traction at the narrow end of the splint, while the ring at the wider end provides countertraction. Many adaptations of the Thomas splint have been made which use the general principle of traction and countertraction.

Now available on the supply table is an adjustable canvas splint called a "universal" splint (fig. A-57). It has parts to make it adaptable for leg, arm, back, and neck. The package contains a leg splint, an outrigger which is adjustable for length, plus two padded wire-mesh splints.

One of these wire-mesh splints has six snaps by which it may be firmly attached to the leg splint, serving to lengthen the leg splint to extend above the hip, and which can be bent around the patient's belt to help prevent exces-

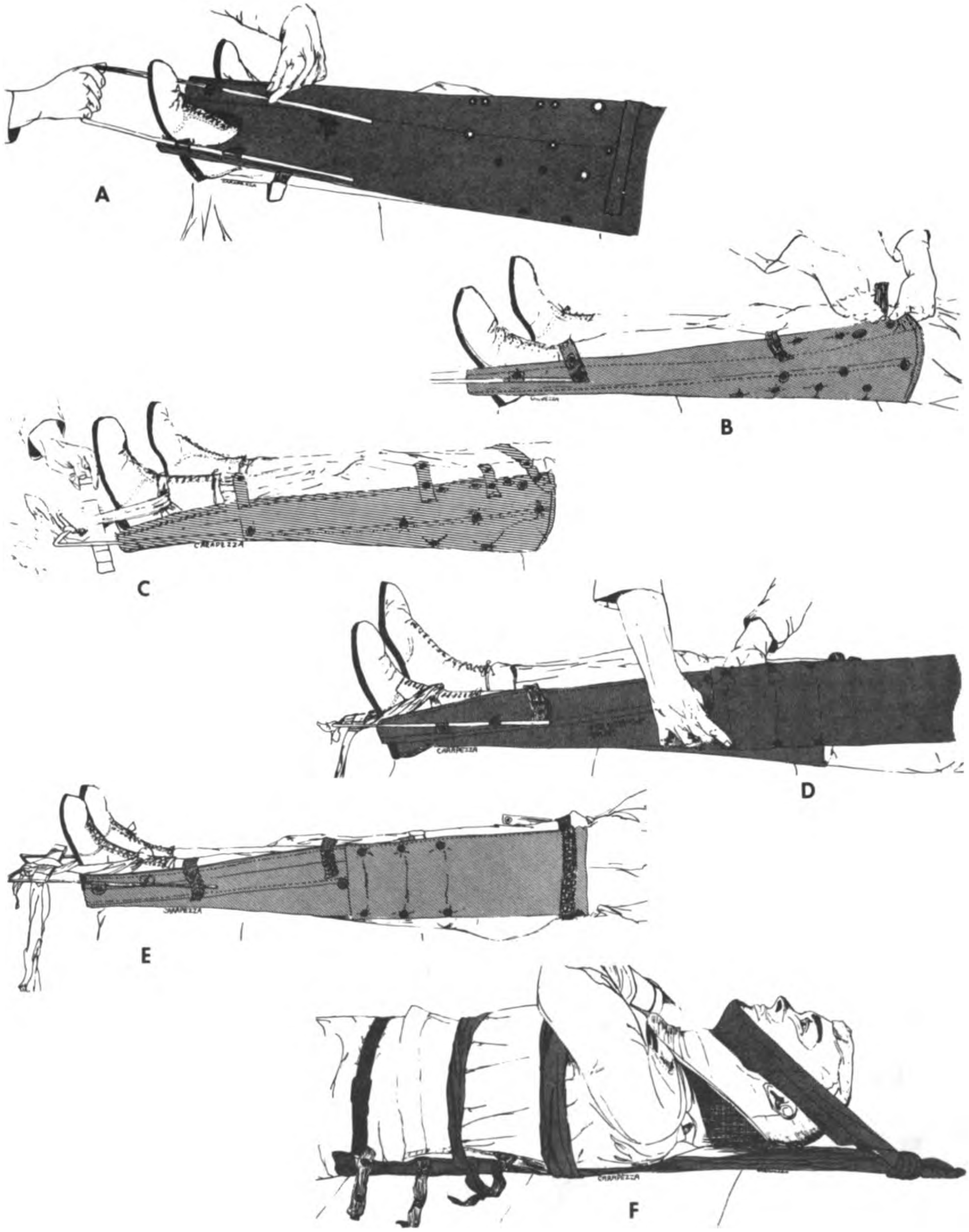


Figure A–57.—**Wraparound canvas splint. A, adjustment of leg length; B, snapping splint in place; C, adding traction by means of Spanish windlass; D, snapping wire-mesh extension to splint; E, wire-mesh extension in place (note cuff turned down over casualty's belt to prevent rotation); F, transportation of those with spinal injuries.**

sive rotation of the fractured leg. The outrigger permits the application of traction, being identical in shape with the narrow end of the conventional Thomas splint. The leg splint can be applied to the body to serve as a semirigid splint in spinal injuries, and the traction attachment can serve as a fixed point for applying neck traction by means of a cravat bandage. The wire-mesh portions can be used singly or together as splints for the upper extremity, or singly as a cervical collar.

No single splint is ideal for all fractures, and this universal splint is no exception. It has the virtue of being in one package and available under field conditions where other splinting materials may be scarce. The wraparound leg splint is one of its most useful components and is easy to apply. It does not, however, hold a fractured femur as rigidly immobilized as the conventional Thomas splint with its countertraction ring.

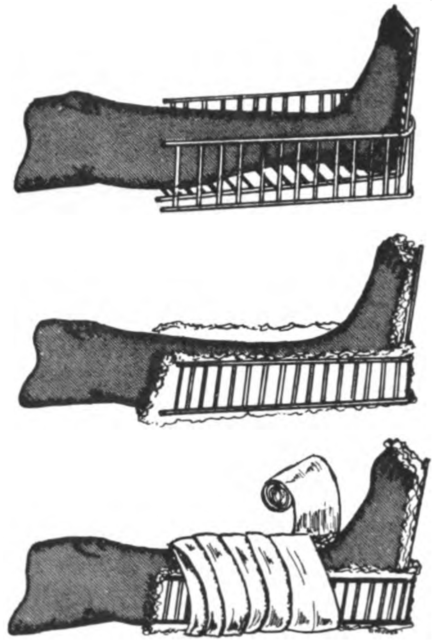


FIGURE A–58.—Wire-ladder splint for ankle.

The wire-ladder splint is very useful also (figs. A–58 and A–59). However, it needs to be well padded before application, for if it is wrapped too tightly, swelling may cause the wire to dig into the skin. This can lead to the development of pressure sores.

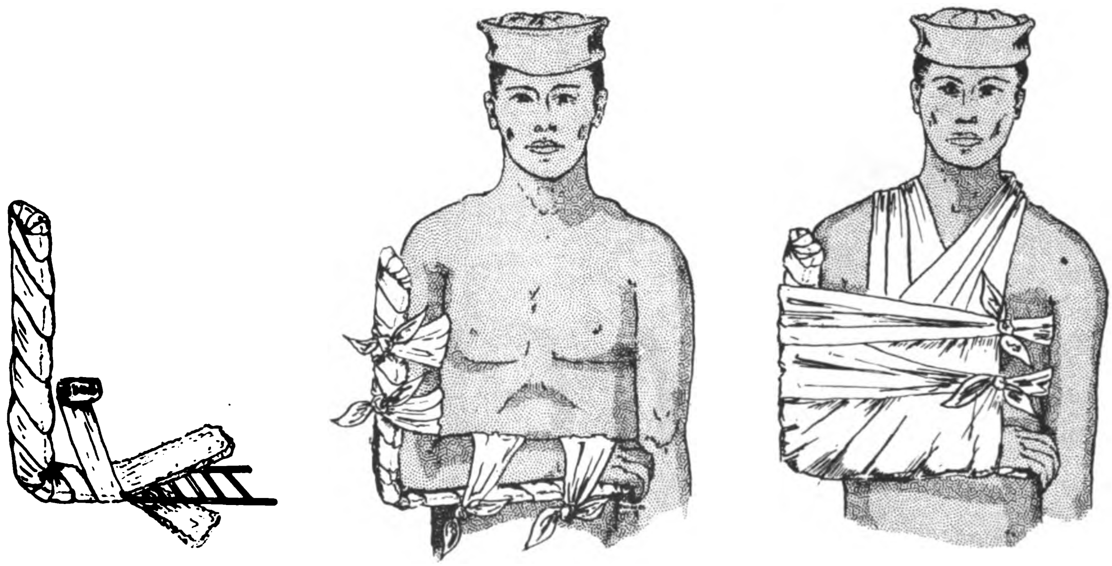


FIGURE A–59.—Wire-ladder splint for upper extremity.

A-L. BANDAGES AND BANDAGING

Bandages are used to hold dressings applied to the surface of the body, to secure splints used in treatment of fractures and dislocations, to create pressure, and to immobilize joints. Various materials are employed, such as gauze, flannel, muslin, linen, and elastic webbing. Gauze is used frequently because it is light, soft, thin, porous, readily adjusted, and easily applied. Muslin is also used frequently, since it is inexpensive and universally available.

A diver should be familiar with the general rules of bandaging and proficient in the application of various types of bandages. The comfort of the patient and the security of the dressing depend upon the proper application of a bandage, for an untidy, uncomfortable, insecure bandage can only result in adverse criticism.

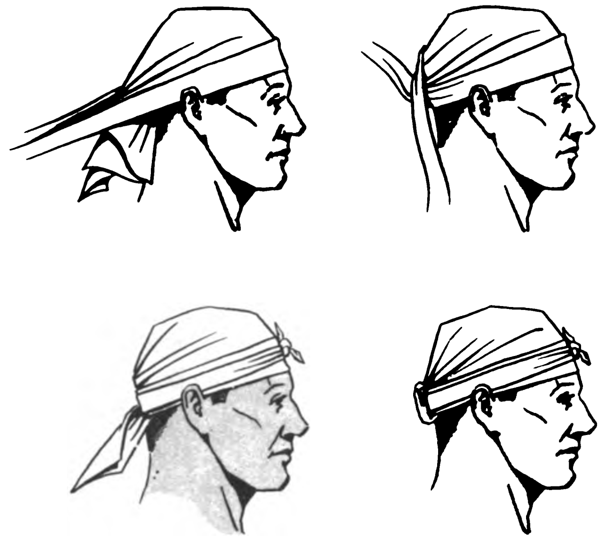


FIGURE A-60.—Triangular bandage for head.

TRIANGULAR BANDAGE

Triangular bandages are generally made of strong material such as muslin. Muslin must be prepared by washing to cause shrinkage, dried and ironed to remove wrinkles. Two full-sized bandages can be made by taking a square yard of material, folding it diagonally, and cutting it in half along the fold. The triangular bandage is very useful in emergencies because it is quickly and easily applied.

Triangular Bandage for Head

When using the triangular bandage to retain dressings on forehead or scalp, the following procedure should be followed (see fig. A-60):

Fold back the base of the bandage about 2 inches, making a hem. Place the middle of the base (hem outside) on the forehead just above the eyebrows. Let the point fall over the head and down the back of the head. Bring the ends of the triangle around the back of the head above the ears, cross them over at the back and carry them around to the forehead, tying them in a square knot. Holding the dressing with one hand, gently but firmly pull down on the point with the other hand until the dressing is snug; then bring the point up and tuck it over and in the bandage where it crosses at the back of the head.

Triangular Bandage for Shoulder

When using the triangular bandage to hold a dressing on the upper arm or shoulder, two triangular bandages are necessary:

Fold the first triangular bandage into a narrow cravat (see fig. A-66). Place the base of the cravat on top of shoulder on injured side and bring ends across back and chest (fig. A-61). Continue on, bringing cravat under opposite axilla around in front. Before tying knot, place a pad in the axilla on the uninjured side to prevent pressure by the narrow cravat. Then tie a square knot. Turn up the base and make a hem of the second triangular bandage and apply it to the arm on the injured side. Carry the ends around behind the arm; cross and tie them in front but not too tightly. Check distal circulation frequently to be sure a tourniquet effect has

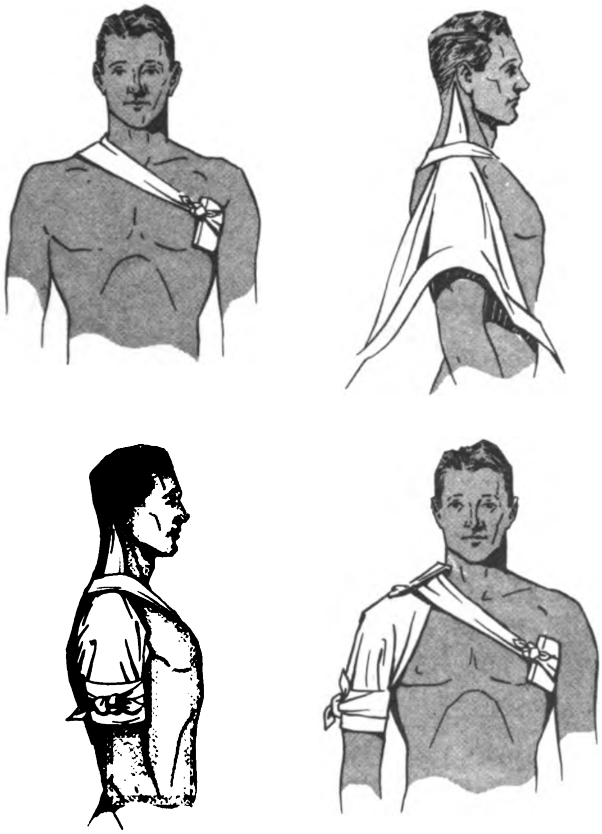


Figure A–61.—Triangular bandage for shoulder.

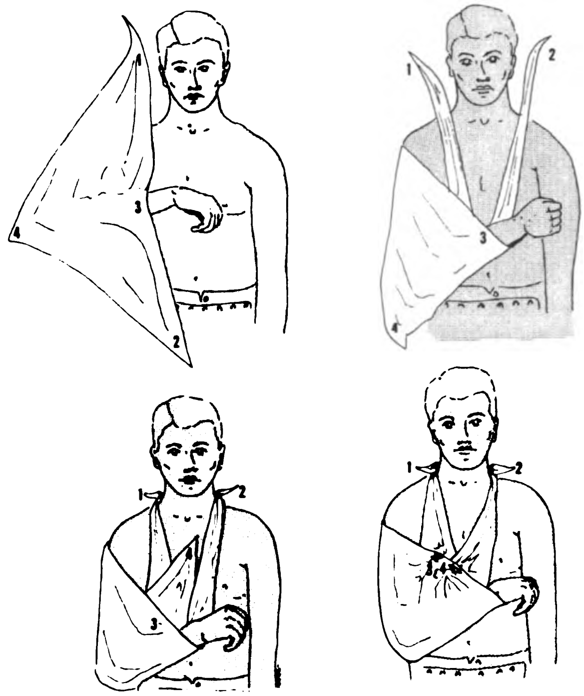


Figure A–62.—Pistol-holster sling bandage.

not been inadvertently created. Support the dressings firmly with one hand, and with the other tuck the point of this triangle under and over the cravat on the shoulder until the dressings are held snugly in place. Pin the point to secure it, or bring the point of the bandage under and around the cravat several times to secure it.

Another adaptation of the triangular bandage for the shoulder is the pistol-holster sling or four-tailed bandage. As seen in figure A–62, the long side of the triangular bandage is laid across the bent elbow. The two long ends are then brought around under the elbow and out again to tie or be pinned about the neck. This accounts for two of the tails. Next a safety pin is placed to fix the long side of the bandage to the original two tails. The fourth tail is the remaining end and this is brought under the elbow and out in front where it is fixed with a safety pin to the other three tails. This makes a comfortable support for the shoulder or upper arm. A swathe made out of cravat bandages may be brought around the chest, adding further support to the shoulder.

Triangular Bandage for Chest or Back

To retain large dressings on the chest (fig. A–63), the triangular bandage may be used as follows:

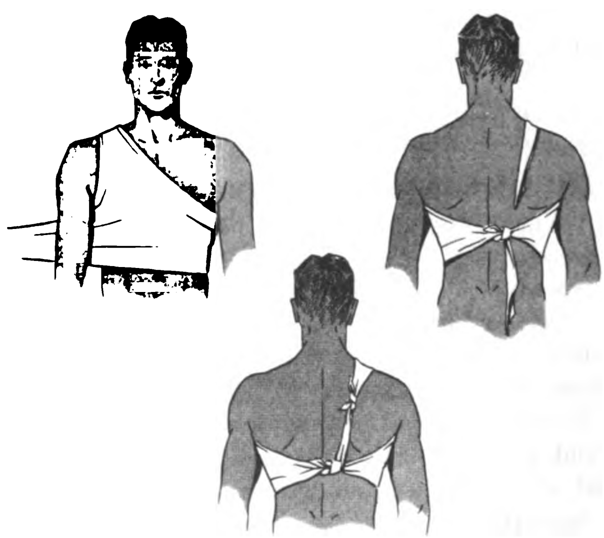


Figure A–63.—Triangular bandage for chest and back.

Drop the point of the triangle over the shoulder on the injured side, letting the base fall down over the injured area. The middle of the base should be directly below the shoulder. Bring the ends around the body to the back and tie them in a square knot directly below the shoulder. This leaves one long end. Tie this long end to the point of the triangle lying over the shoulder. If the base is too low for the wound, it may be shortened by folding it over several times before tying.

For a bandage to retain large dressings on the back, just reverse the above procedure.

Triangular Bandage for Hip

The triangular bandage may also be used to retain dressings on buttock or hip (see fig. A–64).

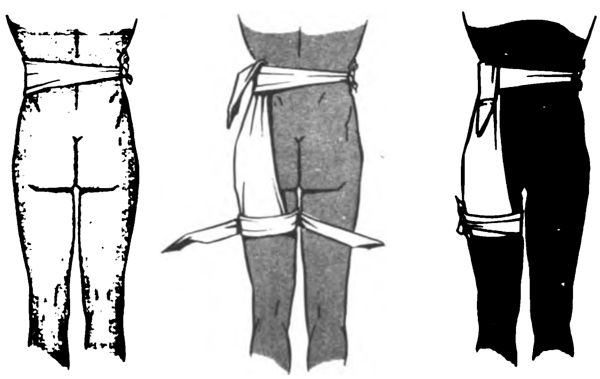


FIGURE A–64.—Triangular bandage for hip.

This requires two triangular bandages. Take the first and make it into a narrow cravat; tie it around the waist with the knot on the uninjured side. Take the second triangular bandage and tuck the point under and over the cravat, letting the base hang down over the thigh on the injured side. Make a hem along its base to the height desired and carry the ends around the thigh, cross, bring around to outside, and tie. With the left hand hold the dressing in place and gently pull the point hooked through the waist cravat until the dressing is well supported. Secure the point with a safety pin or tuck under.

Triangular Bandage for Foot or Hand

This bandage is designed to retain large dressings on the hand or foot (see fig. A–65).

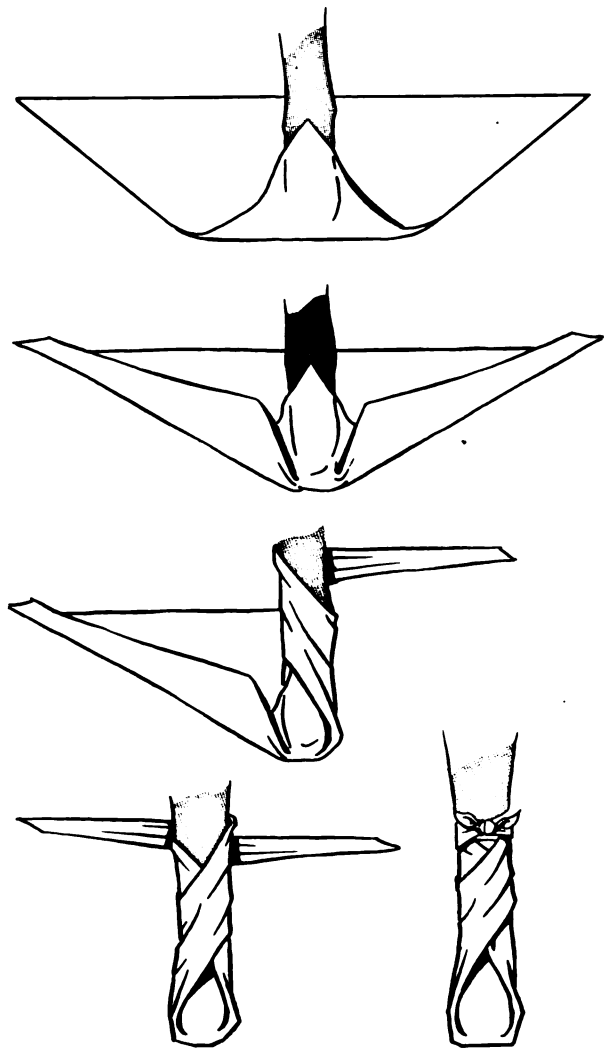


FIGURE A–65.—Triangular bandage for foot or hand.

Place the foot or hand in the center of a triangular bandage and carry the point over the ends of the toes or fingers and on up to the upper part of ankle or wrist. Fold in excess bandage at the sides, cross the ends in front, continue around back, cross, bring around to front, and tie in a square knot.

CRAVAT BANDAGE

To make a cravat bandage, bring the point of a triangular bandage to the middle of the base and continue to fold until the desired width is obtained (fig. A–66).

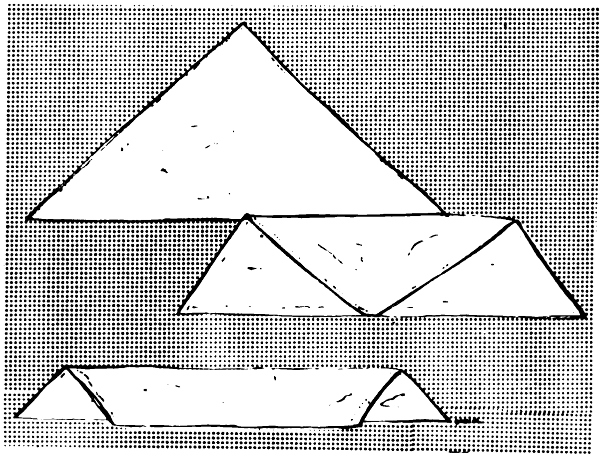


FIGURE A–66.—Making a cravat bandage.

Cravat Bandage for Head

This bandage is very useful to control bleeding from wounds of the scalp or forehead. It is placed over the dressing as follows (see fig. A–67):

Place the center of the cravat over the dressing and bring the ends around to the opposite side, cross them, and continue around to the front. Tie with a square knot.

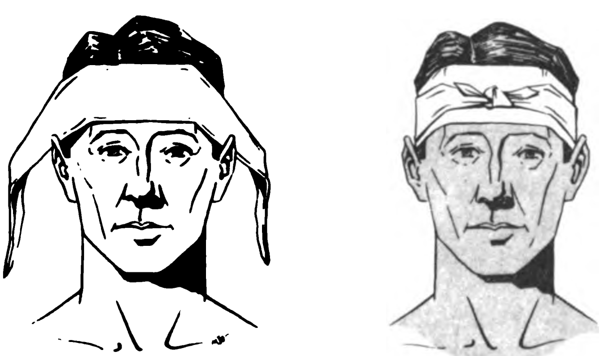


FIGURE A–67.—Cravat bandage for head.

Cravat Bandage for Eye

Place the center of the cravat over the eye dressing on the slant so that the lower end is inclined downward. Bring the lower end around under the ear of the injured side and the other end over the ear on the uninjured side. Cross the ends in back and bring them around to the front. Tie over the dressing (see fig. A–68).

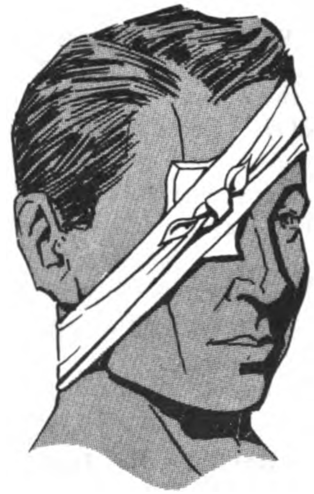


FIGURE A–68.—Cravat bandage for eye.

Cravat Bandage for Temple, Cheek, or Ear

Place the center of the cravat over the dressing and carry one end over the top of the head and the other under the jaw and up the opposite side, crossing at right angles over the temple on the injured side. Continue one end around over the forehead and the other around the back of the head to meet over the temple on the uninjured side. Tie with a square knot (see fig. A–69).

Cravat Bandage for Elbow or Knee

When applying a bandage to the elbow or knee, the joint should be flexed to allow a certain amount of movement. Bend the knee or elbow at the angle shown in the illustrations (see figs. A–70 and A–71). Place the middle of a rather wide cravat over the point of the joint and carry the ends around the upper part of the elbow or knee, bringing it back to the hollow, and the lower end entirely around the lower part, bringing it back to the hollow. See that the bandage is smooth and fits snugly; tie with a knot outside the hollow.

Cravat Bandage for Arm, Forearm, Leg or Thigh

The width of the cravat depends upon the extent of injury and dressing which covers it. For a small area, place the cravat bandage over the center of the dressing (fig. A–72). Bring the ends around in back, cross them back around to the dressing, and tie over it. For a small ex-

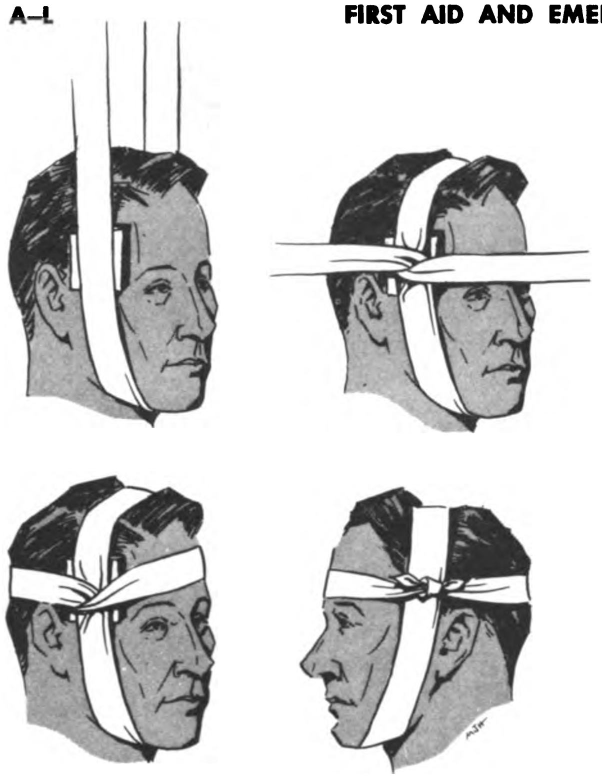


FIGURE A–69.—Cravat bandage for temple, cheek, or ear.

FIGURE A–70.—Cravat bandage for knee.

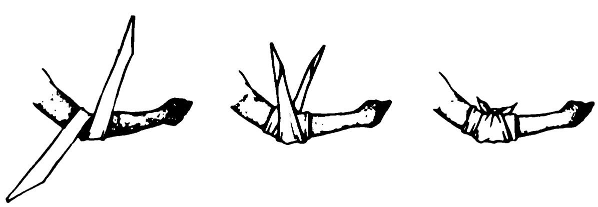


FIGURE A–71.—Cravat bandage for elbow.

tremity, it may be necessary to make several turns before tying. If the wound covers a larger area, hold one end of the bandage above the dressing and wind the other end spirally downward across the dressing until it is secure, then

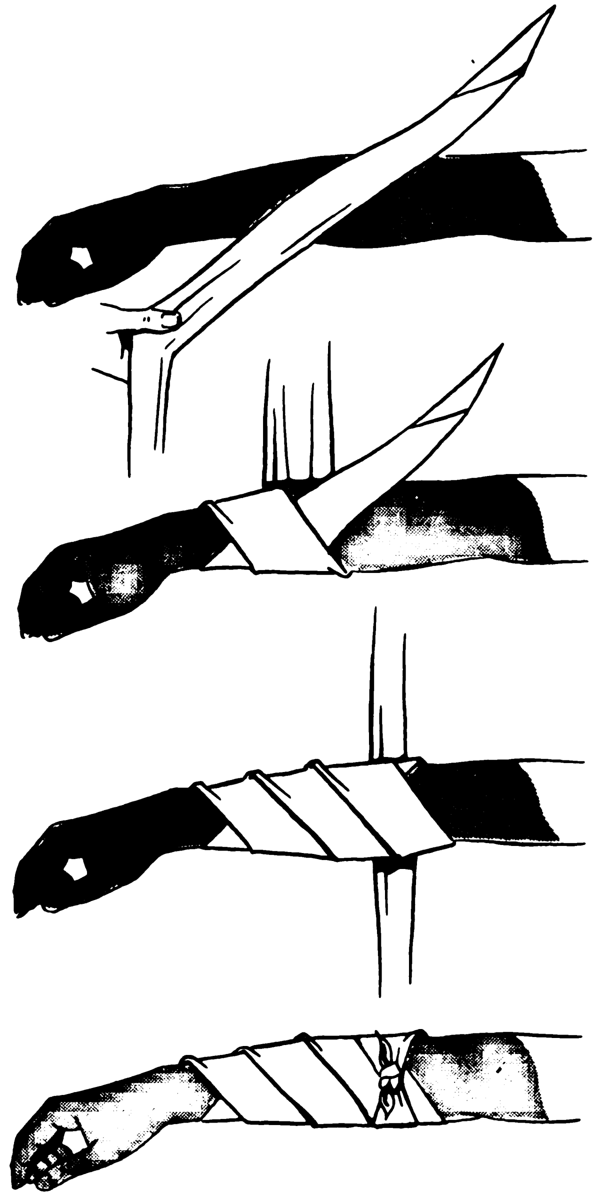


FIGURE A–72.—Cravat bandage for arm, forearm, leg, or thigh.

upward and around again, and tie a knot where both ends meet.

Cravat Bandage for the Axilla

Place the center of the bandage in the axilla over the dressing, carry the ends up over the top of the shoulder and cross them (fig. A–73). Continue slantwise across the back with one end and the chest with the other, over the opposite axilla, and tie them where they meet

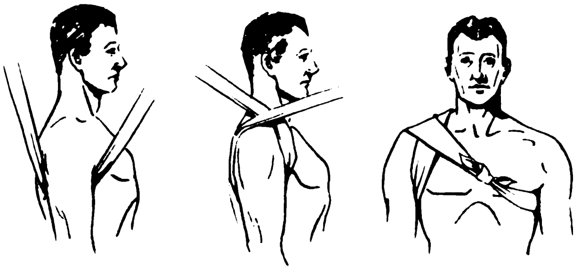


FIGURE A-73.—Cravat bandage for axilla.

over the chest. Do not draw the bandage too tightly or the artery may be compressed, adversely affecting circulation to the arm.

Cravat Bandage for Sprained Ankle

Do not remove the shoe; if the top of the shoe is above the ankle, loosen the laces to allow for swelling. Use a narrow cravat and begin by placing the middle of the bandage under the heel (fig. A-74). Then, bring the ends back and upward crossing above the heel and around forward, crossing over the ankle. Now continue downward and backward again, close to the angle, and put the ends *under* the first turn

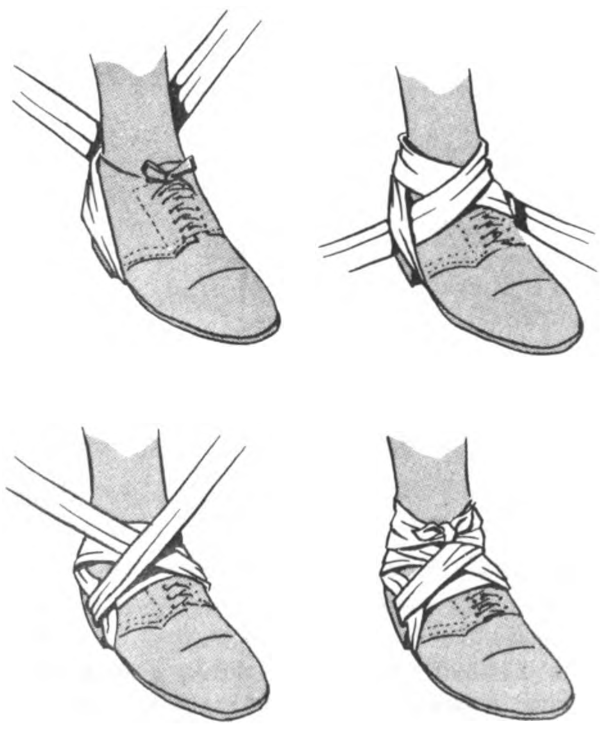


FIGURE A-74.—Cravat bandage for sprained ankle.

making a hitch. Reverse the ends and bring them forward, then back around the ankle once more, and tie in front over ankle.

ROLLER BANDAGE

The roller bandage can be made from gauze, muslin, linen, elastic webbing, or other substances; the width and length vary and depend upon the use it will serve and the part it will cover. The material is rolled for convenience and ease of application, and each roll should consist of a single piece which is free of wrinkles, seams, selvage, and any other imperfections which might cause discomfort to the patient.

Although there are various types of mechanical devices to wind bandages, it is essential that a diver be able to roll a bandage by hand. This is done in the following manner:

Fold strips of the bandage material at one end several times to form a small, firm cylinder. Hold this cylinder by its extremities between the index finger and thumb of the left hand. Between the index finger and thumb of the right hand, hold the free end of the bandage close to the cylinder. With this hand (the right) revolve the material around the cylinder held by the left hand. The amount of tension exerted upon the free end determines the firmness of the completed roll.

Application of a roller bandage.—In applying a roller bandage, hold the roll in the right hand so that the loose end is on the bottom; next apply the outside surface of the loose end to the area to be bandaged and hold it there with the left hand. Pass the roll around the part with the right hand, and control the tension as it is passed around. Two or three of the initial turns should overlie each other in order to secure the bandage and keep it in place. In turning the bandage, transfer the roller from hand to hand; this facilitates the application.

Bandages should be applied evenly, firmly, and not too tightly. Excessive pressure may cause interference with the circulation and may lead to disastrous consequences. It is advisable, therefore, to leave the fingers or toes exposed in order to assess the circulation of these parts. It is also advisable to use a large number of turns to secure a bandage rather than to depend upon a few turns tightly applied.

In applying a bandage that may become wet, as would be expected when its purpose is to keep a wet dressing in place, it is necessary to allow for shrinkage. The turns of the bandage should completely cover the skin—leaving no uncovered areas as they become pinched between the turns when shrinkage or swelling occurs—and should be under less tension than the ordinary wrapping.

In bandaging an extremity, it is advisable to include the whole member (arm and hand, leg and foot), excepting fingers and toes. This is so that uniform pressure can be maintained throughout the limb and the circulation to the part can be assessed by pressure on the nail beds.

The initial turns of a bandage on an extremity should be placed (if at all possible) around the part of the limb that has the smallest circumference. Thus, around the wrist or immediately above the ankle is the site for the start of the bandage; and the final turns should be secured in the same manner as the initial ones; i.e., by two or more overlying circular turns which are then folded over to present a neat, cufflike appearance. The end of the completed bandage is turned under and secured to the final turns by a safety pin or adhesive tape. If these are not available, the end of the bandage may be split lengthwise for several inches, and the two tails tied to secure the bandage.

Roller Bandage for Hand and Wrist

A figure-of-eight bandage is ideal for this area and may be applied as follows (fig. A–75):

Anchor the dressing with several turns of a 2- or 3-inch bandage. If the hand must be bandaged, anchor the dressing with several turns and continue the bandage diagonally upward and around the wrist and back over the palm. Make as many turns as necessary to secure the dressing.

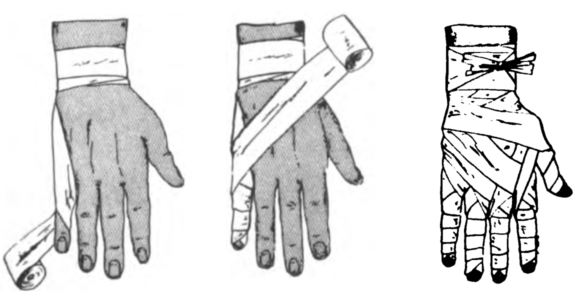


FIGURE A–75.—Roller bandage for hand and wrist.

Roller Bandage for Ankle and Foot

The figure-of-eight bandage is also used for dressings of the ankle as well as for supporting a sprain (fig. A–76).

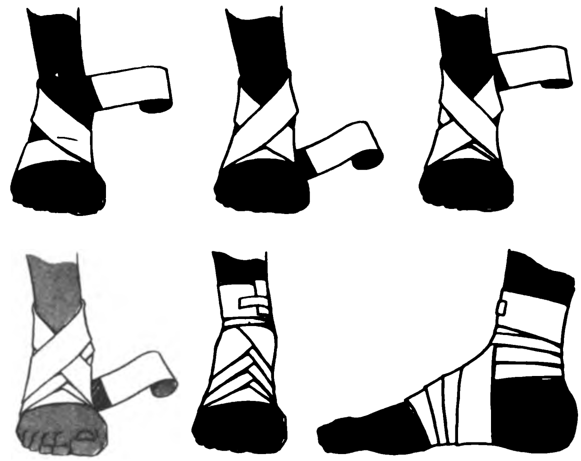


FIGURE A–76.—Roller bandage for ankle and foot.

Keep the foot at a right angle; start a 3-inch bandage around the instep for several turns to anchor it. Bring the bandage up over the instep, around behind the ankle, forward again across the instep and down under the arch, thus completing one figure of eight. Continue with the figure of eights, overlapping one-third to one-half of the bandage's width. Occasionally turn the bandage around the ankle. Make as many turns as necessary to secure the dressing adequately or until adequate support is obtained.

Roller Bandage for Knee

The figure-of-eight bandage of the knee is similar to that of the elbow (fig. A–77).

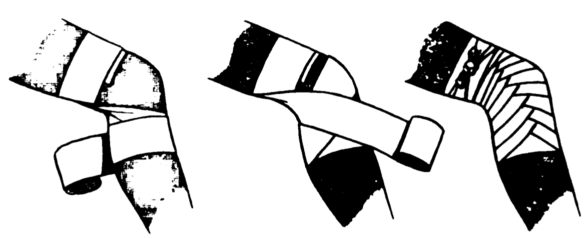


FIGURE A–77.—Roller bandage for knee.

Make two circular turns around the thigh just above the knee and bring the bandage diagonally downward across the kneecap and encircle the leg below the knee with another circular turn. Bring the bandage diagonally upward, again crossing the kneecap to the basic anchor turn. Make another circular turn and repeat the figure-of-eight procedure, overlapping each previous turn about two-thirds of the width of the bandage and gradually ascend the knee. Secure the bandage with several circular turns above the knee and tie. To secure the dressings in the hollow of the knee, reverse the procedure and cross the bandage in the back.

Roller Bandage for Heel

The heel is a very difficult part to bandage securely. Keep the foot at right angles and use the following method (fig. A–78):

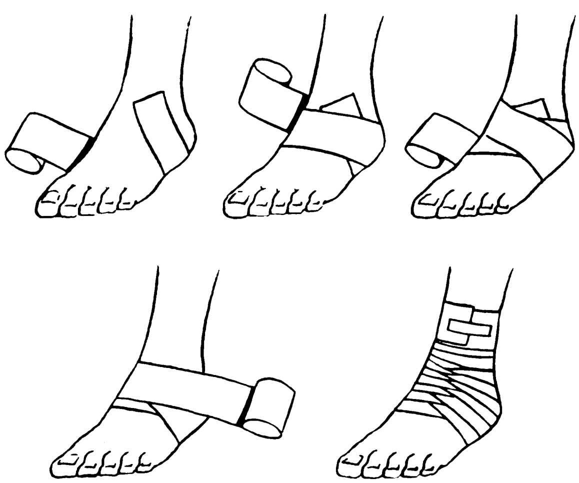


FIGURE A–78.—Roller bandage for heel.

Place the free end of the bandage on the outer part of the ankle and bring the bandage under the foot and over the instep. Then around the heel and back over the instep to the starting point. Overlap the lower border of the first loop around the heel and then repeat—with alternate turns overlapping the upper border of the loop around the heel. Continue with these turns until the heel is well covered and then secure the end with several turns around the lower leg.

Roller Bandage for Elbow

A figure-of-eight type of bandage is recommended to retain dressings in the region of the elbow and to allow a certain amount of movement. The elbow is bandaged as follows (fig. A–79):

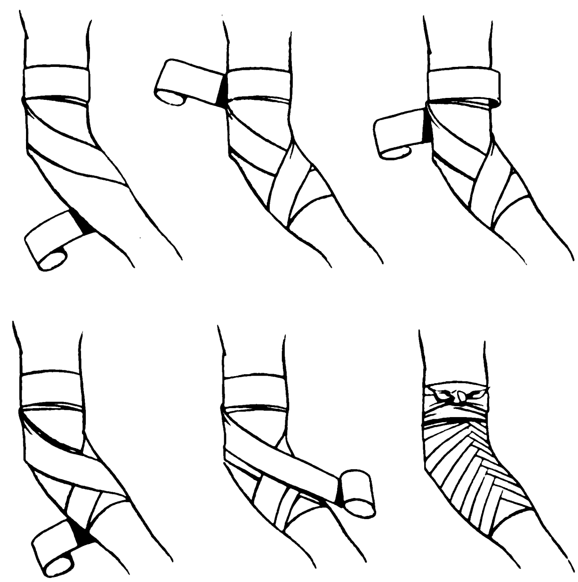


FIGURE A–79.—Roller bandage for elbow.

Flex the casualty's forearm slightly (do not force it if he complains of much pain) and anchor a 2- or 3-inch bandage above the elbow with two circular turns. Bring the bandage diagonally downward across the hollow of the elbow and encircle the forearm below the elbow with a circular turn. Continue diagonally upward across the hollow of the elbow to the starting point. Make another circular turn around the upper arm, bring the bandage downward, repeating the figure-of-eight procedure, and gradually ascend the arm. Overlap each previous turn about two-thirds of the width of the bandage. Secure the bandage with two circular turns above the elbow and secure. If it is necessary to secure a dressing on the tip of the elbow, reverse the procedure and cross the bandage in the back of the arm.

Roller Bandage for Forearm, Leg, and Thigh

The spiral reverse bandage must be used to cover dressings on these parts; only such a bandage can keep the bandage flat and even (fig. A–80).

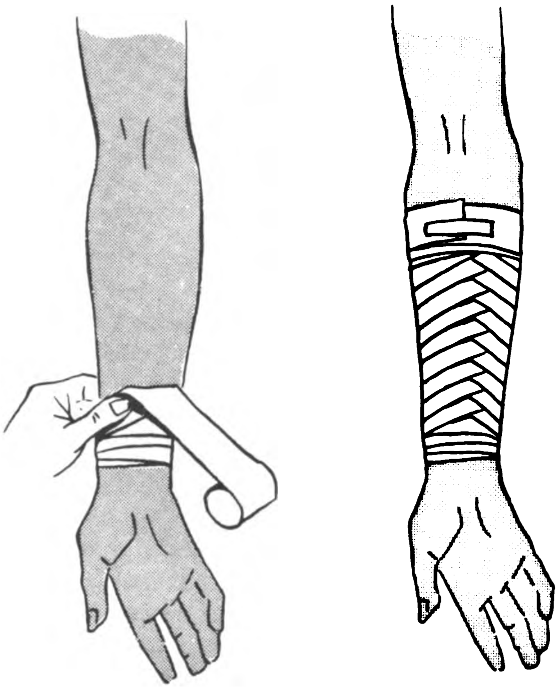


FIGURE A–80.—Roller bandage for forearm, leg, and thigh.

Make two or three circular turns around the lower or smaller part of the limb to anchor the bandage and start upward. Bring the bandage diagonally around the arm, overlapping about one-third to one-half of the width of the bandage and continue wrapping as long as each turn lies flat. When the edge of a turn is loose, it becomes necessary to use the reverse lap. Afterward, continue with the spiral lap making reverse laps only when necessary to maintain a flat, even bandage. Secure the end with several circular turns and adhesive, safety pin, or split tie.

Barton Bandage

The Barton bandage is used to retain dressings of the chin and to provide support of the fractured lower jaw. It is applied as follows (fig. A–81):

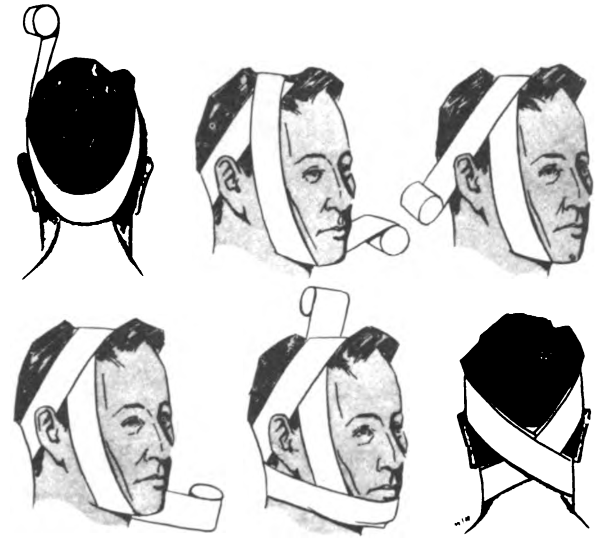


FIGURE A–81.—The Barton bandage.

Place the starting end of the bandage on the head just behind the right mastoid process and bring it up around under the bony prominence at the back of the head, upward and forward back of the left ear, obliquely across the top of the head, downward in front of the right ear, under the chin, upward in front of the left ear, obliquely across the top of the head, crossing the first turn in the midline of the head, thence backward and downward to the point of origin behind the right mastoid. It is then brought around the back of the head under the left ear, around the front of the chin, under the right ear to the point of origin. This pattern is repeated several times, each turn exactly overlying the preceding turn. The bandage is secured with a pin or strip of adhesive tape at the crossing on top of the head.

Roller Bandage for Head

First a gauze pad is replaced over the lacerated area in the scalp, then the bandage (generally of 2-inch gauze) is wound in accordance with the numbered rolls shown in figure A–82.

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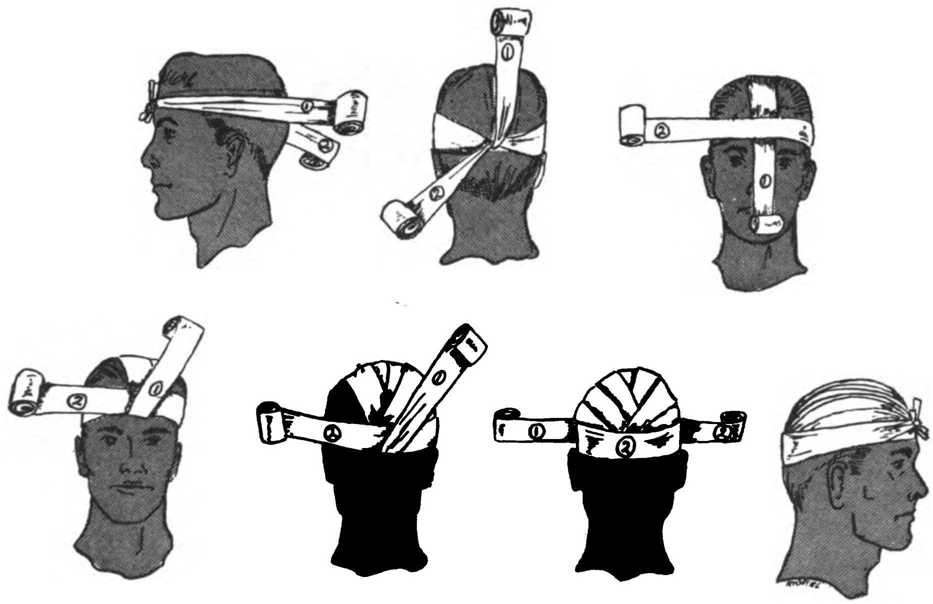

FIGURE A–82.—Roller bandage for head.

A–M. TRANSPORTATION OF INJURED

In a military situation, casualties are generally divided into "walking" wounded and "litter" wounded, for want of better descriptive terms. After the casualty has been examined, positioned according to type of injury, treated for shock if required, and had splints applied when fracture is a consideration, the problem remaining is to move him to where litter bearers or mechanical means of transportation can take him to professional treatment. Inherent in this problem of moving the injured is the strength required for one man to carry or drag another. Under favorable circumstances, the maximum distance one man can be expected to move a helpless individual is about 150 feet; and when the injured is larger than the rescuer, moving him any distance at all is a feat of strength.

The following text, supplemented by illustrations, covers various methods of hand carrying the wounded to litter, ambulance, or shipboard medical facility.

Hand Carry

Drag carry.—Figure A–83 depicts a method for hauling an unconscious patient for a short distance. First the casualty's hands are tied, then placed behind the rescuer's neck.

Blanket drag.—The casualty is placed on a blanket and moved by pulling on one end (fig. A–84). This method is used when the casualty is unconscious and has injuries which forbid handling or lifting by a single bearer.

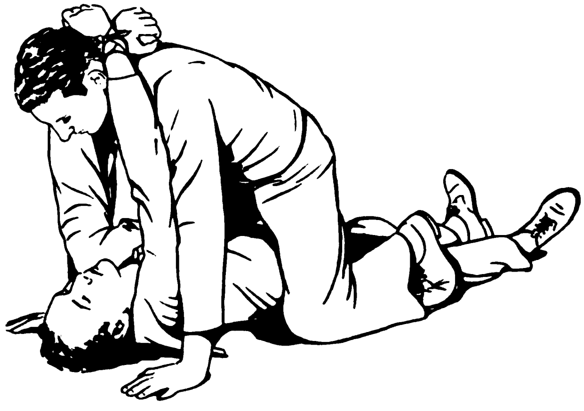

FIGURE A–83.—The drag carry.

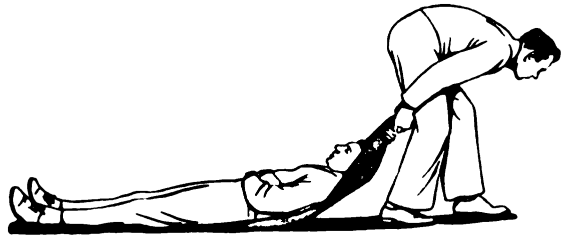

FIGURE A–84.—Blanket drag.

Arm carry.—Another one-man carry for a victim who cannot walk, but is sufficiently responsive to hang on with his arms, is shown in figure A–85.

Fireman's carry.—This one-man carry is probably the easiest way to move an unconscious

FIGURE A–85.—Arm carry.

FIGURE A–86.—Fireman's carry.

patient. Figure A–86 shows the step-by-step positioning of victim and rescuer quite clearly.

Supporting carry.—If the victim is conscious and merely needs support, he may be helped in walking by leaning against another man and putting his arm around his neck. The rescuer in turn holds onto this arm and puts his arm around the waist of the casualty (see fig. A–87).

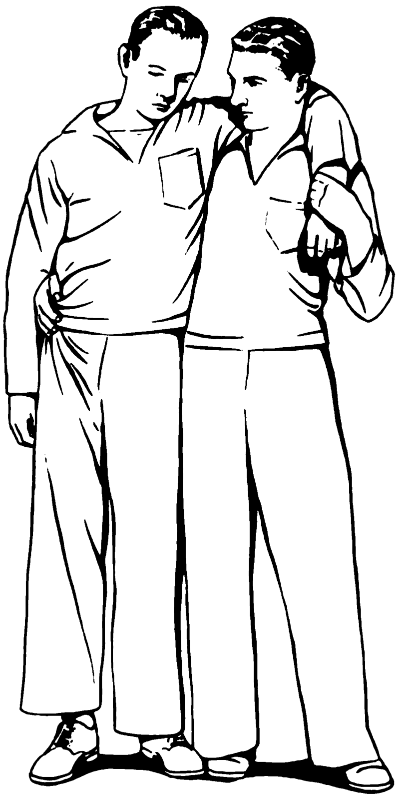

FIGURE A–87.—Supporting carry.

Pack-strap carry.—If the patient is on a bed or in a chair, this carry is convenient. The patient's arms are brought across the shoulders taking care that they are well up; i.e., his armpits rest on the shoulders of the rescuer. His arms are then crossed in front and grasped firmly (fig. A–88).

FIGURE A–88.—Pack-strap carry.

Litter Carry

Army-type litter.—The Army litter is made of canvas and is supported by wooden or aluminum poles. It is collapsible and is most practicable for use in field operations. Figure A–89 depicts this litter and one which may be improvised using coat, shirt, or vest. A blanket wrapped around two poles which have been separated by about 2 feet also may serve as a litter.

Chair litter.—This method requires two men (see fig. A–90). It is valuable for carrying an ill person when litters are ineffective, as through narrow passageways and small doorways.

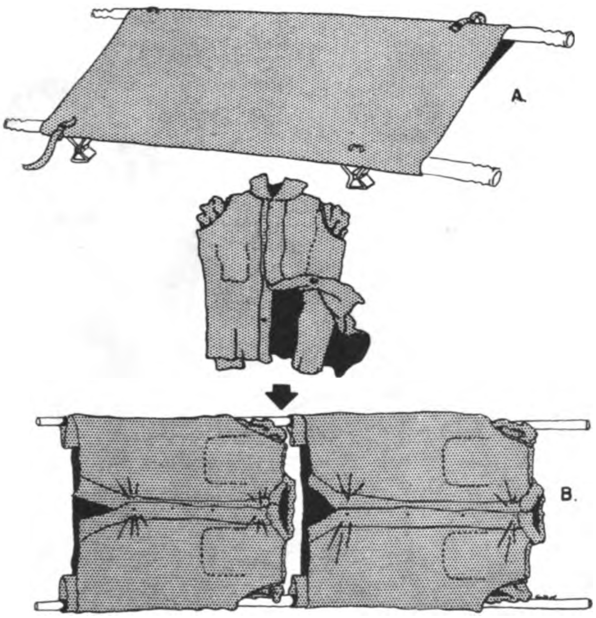

FIGURE A–89.—A, army litter; B, improvised litter.

FIGURE A–90.—Chair used as a litter.

U.S. NAVY DIVING MANUAL

APPENDIX B

TECHNICAL INFORMATION: GAS MIXING, GAS ANALYSIS, AND HIGH-PRESSURE SYSTEMS

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CONTENTS

ILLUSTRATIONS

B–A. GAS MIXING

(1) Mixtures of nitrogen and oxygen and of helium and oxygen required for various purposes in diving have been previously discussed. The preparation of such mixtures and other pertinent information are presented in the following:

Methods

(2) There are two basic methods of preparing compressed-gas mixtures. One involves mixing the component gases by volume in a large gas holder at normal barometric pressure and then compressing the mixture into cylinders. Considerable accuracy is possible with this method because analysis and adjustment of percentage can be accomplished before compression. Because it involves special equipment, this procedure is not feasible except in commercial processes or by a central plant supplying mixtures to a number of operational units.

(3) The only practical methods for field use are those in which the mixing is done with the gases under pressure in cylinders. Here pressure provides the usual basis for proportioning. For example, if a mixture with 50 percent oxygen is desired, half of the intended final pressure must be provided by oxygen. The type of mixture and other circumstances govern the details of the mixing procedures. Several of these procedures are discussed below. Because of difficulties in exact measurement of pressure, temperature effects, and other factors, mixing by pressure is usually not very precise. The resulting mixtures must always be sampled and analyzed, and adjustment of percentage by addition of more than one of the components is often necessary. A procedure of adding one of the gases by accurate weight measurement is sometimes used and has the advantage of reducing temperature effects.

Oxygen-Transfer Pump

(4) Obtaining full pressure in the process of mixing gases or charging scuba cylinders from large cylinders of prepared mixtures often presents problems. One solution is to employ an oxygen-transfer pump. The oxygen-transfer pumps are diaphragm pumps that utilize distilled water or Fluorolube as a pulsing fluid to actuate the diaphragm. The gas and the pulsing fluid do not come in contact during the decompression cycle. Oxygen-transfer pumps are suitable for pumping oxygen or mixtures from a cylinder containing high or low pressure to a cylinder of higher pressure. These pumps are suitable for charging scuba cylinders up to 3,000 psi (noted pressure) and for mixing large volumes of mixed gas. For detailed operation and maintenance instructions, refer to the manual supplied with each pump (see fig. B–1).

Safety Precautions

(5) In dealing with gases under high pressure, all applicable safety precautions must be

FIGURE B–1.—Oxygen-transfer pump.

carefully observed. Those precautions concerning contact between oil and oxygen are particularly important. For example, gages and fittings not specifically intended for use with oxygen often contain oil. When oxygen under high pressure is applied, a violent explosion can occur. Gages for use on oxygen and other mixing equipment must be tested with water, not oil. As an example, a first-class diver was preparing to mix helium and oxygen. He put a new gage, one tested with oil, on an oxygen cylinder. The result was the loss of one eye and multiple lacerations. The diver must not transfer gages from one place to another; for example, a gage previously used on a compressor must not be transferred to a mixing rack.

(6) Precautions regarding oil extend even to the oil deposited by fingers in handling parts of regulators and those other parts exposed to oxygen under high pressure, or to high-pressure streams of oxygen. Use of an oily wrench on an oxygen fitting can start a serious fire. When oily materials must be removed from equipment, only approved cleaning procedures must be employed. When a solvent must be employed, only nonflammable ones like trichlorethylene must be used to assure complete drying before reassembly.

(7) Compressed air that may contain oil vapor must never be mixed with oxygen. Fittings used with air from an oil-lubricated compressor (or any oil-pumped gas) must never be used with oxygen. If an oxygen gage or regulator has been used in this way, it should be painted black and marked AIR ONLY.

(8) In the use of oxygen cylinders, great care must be exercised to prevent contamination by foreign material or other gases. At least 25 psi of oxygen should be left in the cylinder. In particular, an oxygen cylinder must never be charged with air and then returned for refilling with oxygen. Residual oil vapor or an oily film remaining in the cylinder could cause an explosion on recharging the oxygen cylinder unless it was first cleaned by a special and costly procedure. When contamination of any kind has occurred or is suspected, the cylinder must be withdrawn from oxygen service and painted CONTAMINATED (tags or labels are not adequate). If the cylinder is subsequently returned, the nature of the contamination should be specifically called to the attention of the supplier.

(9) Gas under pressure in cylinders, valves, gages, lines, and fittings can be dangerous and should be handled with extreme care. Failure of any functional part can suddenly release the gas with a blast effect similar to that of a high explosive.

(10) In handling cylinders, a suitable truck equipped with a steadying device must be used to keep the cylinders from falling while being moved. The valves must be securely closed with the valve cover caps replaced before moving or storing cylinders.

(11) A wrench or hammer must not be used to open or close cylinder valves. If a valve is too tight to open by hand, a slight steady pressure with an extension tool may be applied to the handwheel, with care being taken not to break the interior parts.

(12) The safety plug should not be tampered with. The plug is designed to relieve excess pressure in the cylinder, and it will fracture at a pressure in excess of the maximum filling pressure.

(13) If the safety plug fractures or blows, it must be replaced only by a plug designed for that particular type of cylinder. Cylinders in stowage, whether empty or charged, should have the threaded protection cap screwed on the threaded connection. The protection cap has the dual purpose of protecting the valve and of preventing any of the fusible metal of the safety plug (if it fractures or blows) from striking and injuring personnel. The valve cover cap should be placed on the cylinders fitted with the protection cap.

(14) The cylinders must be stowed in a dry, cool place away from the direct rays of the sun. They should not be stowed near highly combustible material, especially oil, grease, or any substance likely to cause or accelerate fire. The oxygen cylinders should be stowed well away from cylinders containing another gas. Smoking should be avoided near oxygen cylinders.

(15) All valves, gages, fittings, and lines must be periodically inspected for signs of weakening. All defective or suspected parts must be replaced. Any corrosion or dirt must be cleaned from fittings and valves. Any packing that has been treated with oil cannot be used when repacking valve stems. If the packing recommended by the valve manufacturer is not available, clean, dry, new lamp wicking soaked in pure, clean glycerine should be used.

B-B. HELIUM-OXYGEN MIXING

Single-Cylinder Method

(1) The first step in one method of preparing helium-oxygen mixtures is that of splitting. A full cylinder of helium is connected by means of a mixing T (see fig. B–2) to a cylinder which is empty or nearly so. The stop valve on the full cylinder is opened and the pressure gage on the T-fitting is read. The valve on the empty cylinder is completely opened, as is the valve on the full cylinder, and the pressure is allowed to equalize slowly. The gage reading should then be half its original value. The valves are then closed on the cylinders.

(2) In mixing a single cylinder, a fully charged oxygen cylinder is bled into a helium cylinder which contains helium at the reduced pressure previously mentioned. This requires a T-fitting like that mentioned in the preceding paragraph but with an oxygen connection at one end. Using the T-fitting, a split helium cylinder (about 900 psi) is connected to a full oxygen cylinder (about 1,800 psi). The stop valve on the helium cylinder is opened, the pressure on the gage on the T-fitting is read, then the valve is closed and bled down. The stop valve on the oxygen cylinder is opened and the gage is read.

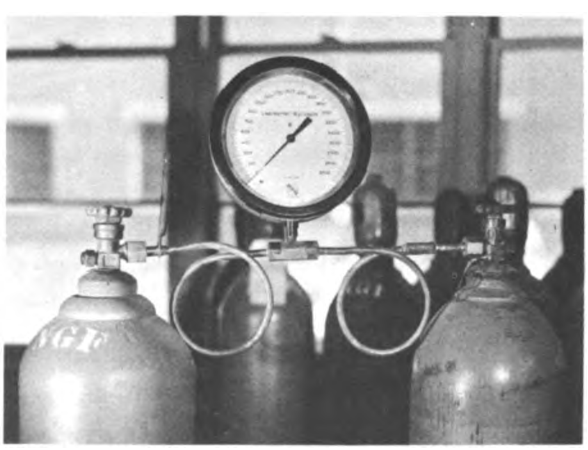

FIGURE B–2.—Helium-oxygen splitting T.

(3) The pressure contained in the helium cylinder when enough oxygen has flowed into it is computed to give the desired percentage:

(*a*) Assume that an 80-percent-helium–20-percent-oxygen mixture is required. The total pressure in the cylinder, after mixing the two gases, is obtained by dividing the pressure in the split-helium cylinder by the percentage (expressed in decimals) of helium in the final mixture.

For example:

Final pressure in mixed-gas cylinder

$$=\frac{\text{Pressure in split-helium cylinder}}{\text{Percentage of helium in final mixture}}$$

$$=\frac{900}{0.80}=1{,}125 \text{ psi}$$

(Pressure exerted by oxygen

$$=1{,}125-900$$
$$=225 \text{ psi}$$
$$=\text{pressure drop in oxygen cylinder.)}$$

(*b*) If an 84-percent-helium–16-percent-oxygen mixture is desired and the split-helium cylinder pressure is 860 psi, then final pressure in the cylinder will be 860/0.84, or 1,024. Pressure drop in oxygen cylinder will be

$$1{,}024-860=164 \text{ psi}$$

(4) In the process of mixing, the helium cylinder heating up and the oxygen cylinder cooling down influence the cylinder pressures (Charles' law). More accurate results are obtained if the oxygen is allowed to enter the helium cylinder slowly (not over 70 psi per minute). Even when this slow rate is maintained, it will be found that when the flow between the two cylinders is stopped and the temperatures are allowed to equalize, the pressure in the oxygen cylinder will have increased slightly and

the pressure in the helium cylinder will have dropped. There is no practical way of controlling the temperature of the gases during mixing, so this temperature effect must be compensated for by exceeding a slight excess of oxygen pressure or by adjusting the cylinder pressures two or three times at intervals after the cylinders have been allowed to return to approximately the same temperature.

(5) To determine whether an oxygen cylinder has enough pressure to permit its use in mixing for a desired percentage of oxygen when the helium pressure is known, the helium cylinder pressure is subtracted from the final cylinder pressure and the remainder is added to the final pressure plus 50 pounds' safety factor.

(*a*)
1,250 (final pressure)
−1,000 (helium cylinder pressure)
250 (lb oxygen added)

(*b*)
1,250 (final pressure)
+250 (lb oxygen added)
1,500
+50 (safety factor)
1,550 (pressure needed in O_2 cylinder)

In other words, the oxygen cylinder must have a pressure equal to the final helium-oxygen pressure plus the oxygen pressure of the mixture—and 50 psi to spare.

(*c*) After determining the final helium-oxygen pressure and the oxygen pressure required for the mixture, the helium cylinder valve must be fully opened and the oxygen valve must be cracked to permit a flow of 70 psi per minute.

Multiple-Cylinder Method

(6) When large quantities of a given mixture must be prepared, much time can be saved by the use of a multiple-cylinder mixing and splitting rack. An example of such an arrangement is diagramed in figure B–3. The basic principle of mixing with a rack is the same as that of the single-cylinder method, as is the calculation method.

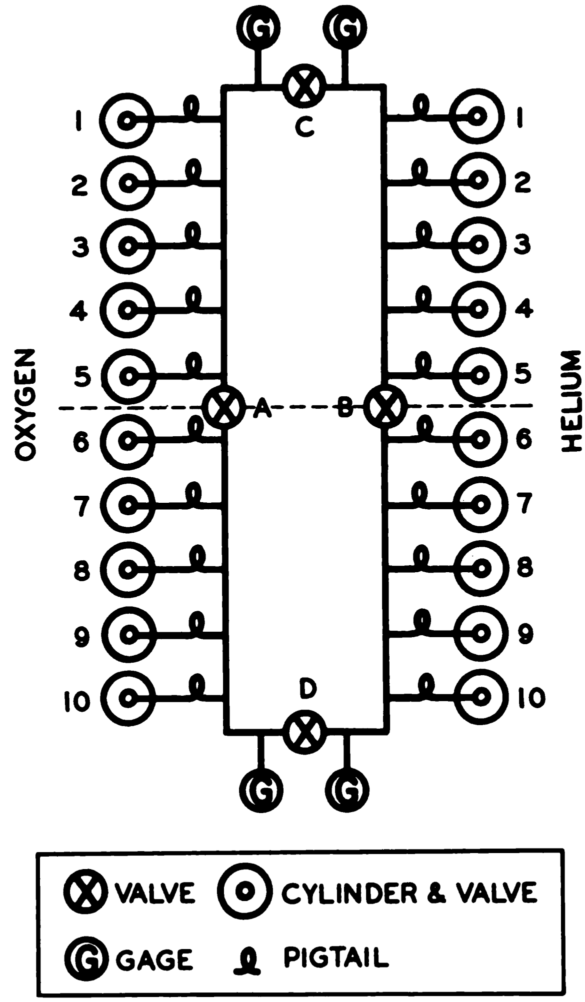

FIGURE B–3.—Helium-oxygen multiple-cylinder mixing manifold.

(7) The usual steps in using a mixing and splitting rack like the one shown in figure B–3 are as follows:

(*a*) Connect 10 full oxygen cylinders to one side of the rack.

(*b*) Close valves A, C, and D.

(*c*) Open all cylinder valves; then crack valve A to permit pressures to equalize in all the oxygen cylinders.

(*d*) On the other side of the rack, connect five full helium cylinders in positions 1 to 5, and five that are empty or nearly so in positions 6 to 10.

(*e*) Close valve B and open all cylinder valves; then crack valve B to let all 10 cylinders equalize (splitting).

(*f*) Allow temperatures to stabilize.

(*g*) By cracking valve C or D (or both, if two operators are used), bleed oxygen into the helium cylinders to the desired pressure.

(*h*) Adjust pressure as described in the single cylinder method.

Adjustment of Percentage

(8) If it is necessary to increase the oxygen percentage of a previously mixed cylinder, follow these steps:

(*a*) Subtract the known percentage of oxygen from 100 to obtain the existing percentage of helium.

(*b*) Multiply the helium percentage by the cylinder pressure to obtain the pressure of helium in the cylinder.

(*c*) Subtract the desired oxygen percentage from 100 to obtain the desired percentage of helium.

(*d*) Divide the existing helium pressure (step (*b*)) by the desired helium percentage (step (*c*)) in decimal form. (This step yields the cylinder pressure that will exist when enough oxygen has been added to yield the desired percentage.)

(*e*) Add oxygen until this pressure is reached. (Allow temperature and pressure to stabilize and add more oxygen if necessary.)

(*f*) The following formula sums up the computation:

$$F=\frac{P\times(1.00-Oo)}{(1.00-Of)}$$

where

F=final cylinder pressure

P=original cylinder pressure

Oo=original oxygen percentage (decimal form)

Of=final oxygen percentage (decimal form)

(*g*) Example:

For a cylinder containing 1,000 psi of a 16-percent-oxygen mixture, with a 20-percent-oxygen mixture desired

$$F=\frac{1{,}000\times(1.00-0.16)}{(1.00-0.20)}=\frac{1{,}000\times0.84}{0.80}=\frac{840}{0.80}=1{,}050\text{ psi}$$

Therefore, add 50 psi of oxygen to obtain a cylinder pressure of 1,050 psi.

(9) To reduce the oxygen percentage, use this procedure:

(*a*) Multiply oxygen percentage (decimal form) by the cylinder pressure to obtain psi of oxygen pressure.

(*b*) Divide this figure by the desired oxygen percentage (decimal form). This yields the final pressure to be obtained by adding helium.

(*c*) Formula (symbols as in (8) above):

$$F=\frac{P\times Oo}{Of}$$

(*d*) Example:

For a cylinder containing 1,000 psi of a 20-percent-oxygen mixture, with a 16-percent-oxygen mixture desired

$$F=\frac{1{,}000\times0.20}{0.16}=\frac{200}{0.16}=1{,}250\text{ psi}$$

Therefore, add 250 psi of helium to obtain a cylinder pressure of 1,250 psi.

(10) The above mixing procedures also apply to mixing by means of the oxygen-transfer pump. Instead of being bled directly from an oxygen cylinder into a helium cylinder, oxygen may be drawn from a cylinder at low pressure by the oxygen-transfer pump and discharged into the helium cylinder until the proper cylinder pressure is reached. This allows the use of most of the oxygen in the cylinder and is therefore more conservative in gas usage.

B–C. GAS ANALYSIS

(1) When gas mixtures are used for diving, an accurate determination of oxygen concentration (percentage) is necessary. Any significant deviation from the planned or assumed oxygen content can produce serious difficulties. Personnel responsible for mixing and analyzing gases must be extremely careful and accurate in their procedures. They must have comprehensive knowledge of gas mixing and analyzing. They must maintain complete records of mixing and analysis operations, check the accuracy of the work, and eliminate any errors in procedure and technique.

Methods

(2) Every gas has certain chemical and physical properties that distinguish it from other gases and permit it to be identified and measured. For example, carbon dioxide is absorbed by alkaline solutions. Other gases likely to be present in breathing media are not, so this reaction provides a means of analysis for carbon dioxide. Similarly, oxygen is absorbed by a pyrogallol solution. This also absorbs carbon dioxide; but if CO_2 is absent or is absorbed separately first, the oxygen content of a sample can be determined. These reactions form the usual basis for chemical gas analysis in diving. For years, *chemical* methods of analysis, such as those using the Maldane analyzer, where the only practical field procedures.

(3) Instruments developed in more recent years use physical properties of gases as a basis of analysis. Some of these are able to analyze gases almost instantaneously and to provide a record of the concentration of a gas in a continuously flowing sample. Such instruments have many applications in industry and research. One, the Beckman oxygen analyzer (see app. B, secs. D and E), has greatly simplified gas analysis in diving. However, it is a delicate instrument and it can be easily broken or put out of adjustment by mishandling; it requires periodic calibration. Therefore, it has not completely replaced older methods, and technicians must be familiar with both methods of analysis.

Gas Sampling

(4) The accuracy of a gas analyzer or method of analysis is nullified if the sample of gas analyzed becomes contaminated. For example, the results of gas analysis will be completely invalidated if air is allowed to mix with sample as it is drawn or tested. Regardless of the method of analysis employed, appropriate sampling devices must be used, and careful attention must be given to both sampling and transfer procedures.

B–D. BECKMAN MODEL C OXYGEN ANALYZER

(1) The instrument supplied for shipboard use by ASR's for analysis of helium-oxygen mixtures is the Beckman Model C oxygen analyzer (see fig. B–4). The Beckman analyzer employs a physical property of oxygen as the basis of analysis. No solutions or chemicals are used, so the sample remains unchanged after passing through the instrument. The analyzer can be used satisfactorily aboard ship unless motion and vibration are unusually strong. The manufacturer claims an accuracy of plus or minus 1 percent of the full scale, but greater precision is possible when accurate calibration is obtained and all other details of technique are carefully observed. Most of the Beckman Model C instruments used in diving are designed for the range between 0 and 25 or 10 and 25 percent oxygen. Thus, they are unsuitable for analyzing high-oxygen mixtures. However, other ranges can be obtained. The main drawback of the Beckman analyzer is that it is a rather delicate instrument from the standpoint of rough handling, but many of the analyzers have given years of trouble-free performance with reasonable care.

Principle of Operation

(2) The heart of the Beckman analyzer is an extremely small dumbbell-shaped test body made of glass suspended on a quartz thread. The dumbbell is centered in the analysis cell of the instrument. Two large permanent magnets terminating in shaped pole pieces above and

Figure B–4.—Beckman oxygen analyzers. Left, model D; right, model C.

below the spheres of the dumbbell produce strong magnetic fields around them.

(3) Oxygen is strongly paramagnetic (attracted by a magnetic field). This physical property of oxygen forms the basis of analysis. The oxygen molecules in a sample of gas are attracted into the magnetic field and actually tend to displace the spheres. This forces the dumbbell to rotate. The suspended quartz fiber resists being twisted, so the final position of the dumbbell represents a balance between the force of oxygen molecules being attracted into the field and the torsion of the fiber. The more oxygen molecules present, the more the dumbbell is displaced.

(4) A small mirror is mounted on the dumbbell, and a narrow beam of light is reflected from this mirror to the translucent scale on the front of the analyzer. As the dumbbell rotates, the light beam moves across the scale.

(5) The rotation of the test body, and thus the deflection on the scale, is proportional to the number of oxygen molecules present. In other words, the rotation is proportional to the partial pressure of the oxygen in the analysis cell. Note that several factors besides the concentration (percentage) of oxygen in the sample will influence the partial pressure of oxygen. These include—

(*a*) The atmospheric (barometric) pressure.

(*b*) Any excess pressure (or vacuum) in the sample cell.

(*c*) The temperature of the gas.

(*d*) The amount of water vapor present.

(6) The scale of the instrument is usually marked off in percent, but a given reading is accurate in terms of percent only if these factors all have the intended values. Some of these factors can be controlled, but others require the use of correction factors. They are discussed in the following paragraphs.

(7) The instrument is designed to read correctly in percent at a barometric pressure of 760 mm Hg (29.92 in. Hg). Consequently, the barometric pressure at the time of analysis must be known. If it differs more than a small amount from 760, a correction factor must be employed. (See (30) and (33) below.)

(8) Running a sample through the analyzer at an excessively rapid rate will increase the pressure in the cell. For this reason a rate between 50 and 250 cc per minute is recommended. (If there is no convenient method of measuring the flow, stop the inflow briefly while taking a reading.)

(9) To eliminate errors due to temperature, the Beckman Model C analyzer has thermostatically controlled heaters on the sample cell. Samples are automatically warmed to a standard temperature higher than any room temperature likely to be encountered. The pilot light on the front of the instrument glows when the heaters are on and goes off when the proper temperature has been reached. Readings taken when the light is on may be inaccurate. The instrument will operate properly at any room temperature between 40° and 105° F. Warmup requires about 30 minutes when the analyzer is first turned on.

(10) Water vapor in a sample increases its volume and decreases the partial pressure of oxygen. Samples drawn directly from high-pressure cylinders without any contact with water are generally quite dry, so this is usually not a problem. Samples from wet sources (including room air) should be run through a drying tube filled with fresh silica gel, or another drying agent, on their way to the analyzer.

(11) Another complicating factor in the use of the Beckman analyzer concerns the diamagnetic effect of gases other than oxygen. If a given percentage of oxygen is present in helium, the reading will differ slightly from that obtained with the same percentage in nitrogen. The diamagnetic molecules are repelled by the magnetic field and move away from it. This somewhat offsets the sphere-displacing effect of the oxygen molecules. Because nitrogen molecules are more diamagnetic than helium molecules, the instrument will give a slightly lower reading with nitrogen as the background gas than with helium. Methods of correcting for this possible source of error are discussed in (28) and (29) below.

(12) In most Beckman Model C analyzers in field use, the fragile test body and its suspension are protected from possible damage from excessively high sample flow rates. This is accomplished by placing a porous filter in the analysis cell. Time is required, therefore, not

only for flushing the cell but also for the sample to diffuse through the filter. More than a minute usually elapses before the analyzer fully responds to a change in sample composition. The operator must be sure that it has completely stabilized before taking a final reading.

Precautions

(13) It is quite possible for a Beckman oxygen analyzer to get out of adjustment and give erroneous readings, even under ideal conditions. Therefore, complete accuracy requires checking the calibration of the instrument periodically and either making certain adjustments or preparing a calibration graph (or both). Methods for doing this are described in (18) and (33) below.

(14) A Beckman oxygen analyzer is not readily damaged except by rough handling. The sample cell will withstand negative and positive pressures between complete vacuum and 15 psi. Although excessively high flows of a sample should be avoided, they will usually not cause damage. Sudden surges of pressure should be avoided. Trying to analyze a sample whose oxygen concentration is beyond the range of the instrument will cause the reading to go off the scale, but will not harm the analyzer.

(15) The fragility of the test body and the quartz-fiber suspension is such that jarring the instrument (by setting it down hard or by bumping it against something) can cause damage requiring factory repairs. Flooding the instrument with water or using excessively moist samples can also cause serious damage. Mercury, dust, and corrosive gases must also be avoided. Maintenance is generally simple. (See (41) below.)

Setting Up

(16) Preparing the Beckman Model C analyzer for use involves these steps:

(*a*) Place it on a firm shelf or table in a location as free from motion and vibration as is practical.

(*b*) Plug the power cord into a 115-volt, 50- to 60-cycle, alternating-current source.

(*c*) Turn the instrument on and allow it to warm up for about 30 minutes.

(*d*) Arrange sampling connections, making sure that flow can be controlled readily. Put a flowmeter in the line if possible.

(*e*) Especially if the sample is from a source other than compressed-gas cylinders and is possibly moist, insert a drying tube (containing fresh silica gel, activated alumina, or another drying agent) in the line. The routine use of a drying tube is good practice.

(*f*) If the sample contains dust or other foreign matter, insert a filter. (A wad of glass wool in the end of a drying tube is satisfactory. Such a filter must be used if a drying agent is employed to prevent any carryover of dust or particles of absorbent.)

(*g*) If warm gas is to be analyzed (over 110° F), provide a coil of metal tubing to cool it. If the warm gas is also moist, provide a trap upstream from the drying tube to collect the moisture that condenses when cooling.

(*h*) Connect sample tube to one of the metal nipples in the lower right-hand corner of the face of the instrument.

Operation

(17) Before actual analysis of samples, the calibration of the instrument must be checked and adjustments made or a calibration graph prepared. (See (18) and (33) below.) When this has been done, the operator can proceed according to these steps:

(*a*) Run sample through instrument at a flow rate between 50 and 250 cc per minute.

(*b*) Observe the reading and wait until it stabilizes (usually at least 1 minute).

(*c*) If pilot light is glowing, wait until it goes out before taking reading.

(*d*) If not sure flow rate is correct, interrupt flow while taking reading.

(*e*) Take final reading and record it. (Read one edge of the light beam for maximum precision.)

(*f*) Determine barometric pressure and record it.

(*g*) Make corrections for barometric pressure, background gas effect, and calibration errors as required (see below).

Calibration

(18) Sometimes when the Beckman analyzer is moved (and sometimes for no evident reason), the relationship between the true oxygen percentage or partial pressure and the scale reading will shift. If such a shift occurs and is not discovered, and if some means of compensation is not employed, all analyses will be incorrect. The term "calibration" here indicates the process of checking and compensating for such errors. Checking requires putting samples of a gas whose oxygen concentration is known in the instrument and seeing what readings are obtained. There are several methods of correcting or compensating if errors are found.

(19) Several types of errors in calibration are possible:

(*a*) The readings may shift up or down the scale. For example, 0 percent oxygen might read 1 percent, while 20 percent oxygen would read 21 percent. If such an error is found, the instrument can be readily adjusted. In the meantime, the amount of error can simply be added to, or subtracted from, the readings.

(*b*) The span may change. For example, 0 percent oxygen might read 1 percent, while 20 percent would read 19 percent. The instrument could be adjusted so that 20 percent would read 20 percent on the scale, but then the lower part of the range would be even farther off. This type of error cannot be corrected by simple addition or subtraction, and requires a calibration graph.

(*c*) Both the above types of error can occur in the same instrument.

(*d*) A type of error more difficult to compensate is an irregular one. Fortunately it is seldom if ever seen in the Beckman analyzer. For example, the scale readings might be correct from 0 to 15 percent and incorrect from 15 to 25 percent. The calibration procedures described here assure that this type of error will not be encountered. Should it ever be discovered, the instrument should be returned to the factory for recalibration.

(20) The calibration process requires the use of at least two known samples, preferably close to the extremes of the instrument's range. Because fresh air has a constant oxygen concentration (20.94 percent), it is a good mixture for the high point in calibration of a 0- to 25- or a 10- to 25-percent instrument. (It should also be used as an intermediate checkpoint in calibration of a 0- to 100-percent analyzer.) Pure helium or pure nitrogen can be used to obtain a zero point. Oxygen serves as the high point for a 0- to 100-percent instrument (pure oxygen can be assumed to contain at least 99.5 percent oxygen). Note that no gas mixing or analysis by other means is required if the gases mentioned suffice for calibration. However, a 10- to 25-percent Beckman analyzer requires preparation and careful analysis by a laboratory of a calibration mixture with an oxygen concentration slightly above 10 percent to use for the low point.

(21) With suitable gases in hand for calibration, the next step is to determine what readings these gases should yield if the analyzer is properly calibrated. This first requires a decision whether the instrument is to be calibrated for nitrogen-oxygen mixtures or for helium-oxygen mixtures. If a 0- to 25- or a 10- to 25-percent analyzer were originally calibrated for nitrogen and it still has the proper span (see (19(*b*) above), it may prove more convenient to retain the nitrogen calibration even though only helium-oxygen mixtures will be analyzed. Otherwise, the background gas to be most frequently encountered should determine the calibration. Once this decision is made, it is possible to specify what readings should be obtained at a barometric pressure of 760 mm Hg (29.9 in. Hg). Then, if the barometric pressure differs from the 760 on the day of calibration, this difference must be taken into account.

(22) Proper readings for various calibration gases at 760 mm Hg can be specified or determined as follows:

(*a*) Pure nitrogen should read zero on a nitrogen-calibrated instrument; it should read minus 0.3 percent on a helium-calibrated instrument. (This shows the greater diamagnetic effect of nitrogen. Any reading below the scale will have to be estimated as accurately as possible.)

(*b*) Pure helium should read +0.3 percent on a nitrogen-calibrated instrument and zero on an instrument calibrated for helium.

(*c*) Fresh air should read 20.9 percent on a nitrogen-calibrated analyzer and 20.7 percent on a helium-calibrated instrument. (It is not difficult to estimate to the nearest 0.1 percent on 0- to 25- and 10- to 25-percent instruments, but it is impossible to read to the second decimal place. Therefore, all readings and corrections can be rounded to the nearest 0.1 percent.)

(*d*) Pure oxygen should read between 99.5 and 100 percent on any 0- to 100-percent instrument.

(*e*) If another concentration of oxygen must be used for calibration, the mixture should be prepared by a laboratory using the background gas for which the instrument is to be calibrated.

(23) The reading that should be obtained with a calibration gas at a barometric pressure other than 760 mm Hg can be determined with this formula:

$$R_b = R_{760} \times \frac{B}{S}$$

where

R_b = correct reading at a barometric pressure other than 760 mm Hg.

R_{760} = correct reading at 760 mm Hg (see (22)).

B = barometric pressure at time of calibration (inches or mm of Hg).

S = standard barometric pressure (760 mm Hg or 29.9 in. Hg—use same units as for B).

(Barometric pressure makes no significant difference when no oxygen is present in the gas, so no barometric correction for the zero reading is needed.)

(24) The operator should proceed to obtain readings with the calibration gases, observing the details of technique described for analysis in (16) and (17) above. If the readings are within about 0.2 percent of their correct values, the instrument's calibration can be considered satisfactory for most purposes and the readings used directly. (Correction for barometric pressure and background gas is still required in actual analysis as discussed in (28), (30), and (31) below.)

(25) If the error observed is simply a shift up or down the scale (the same amount of shift at both points), adjustment of the instrument is worthwhile. The steps of adjustment are as follows (the process is simplified by working in a darkened room because the light beam will not show on the scale in broad daylight when the cover is removed):

(*a*) Remove cover. (Be careful not to jar the instrument in the process. Avoid touching the aluminum mirrors inside.)

(*b*) Have one of the calibrating gases running slowly through the analyzer.

(*c*) If the shift is large, loosen the lamp arm clamp and move the analyzer lamp assembly so that the reading comes close to the correct one for the gas being used. Retighten the clamp.

(*d*) If the shift is small, or after a gross adjustment has been made as in (*c*) above, find the small hole in the block between the two magnets above the analysis cell. Take an allen wrench (of the same size that fits the keyway on the lamp body) and insert it deep into this hole until it engages the keyway in the adjusting screw. Turn to make fine adjustments. Hold the wrench firmly when getting it close to the magnets.

(*e*) When one of the calibration points has been adjusted in this way, try the calibration gas that produces a reading toward the opposite end of the scale. Note whether it now gives the correct reading. (If it does not, you are dealing with more than a simple scale-shift error.)

(*f*) Recheck readings and replace cover so that it is firm and tight.

(*g*) Recheck again after replacement of cover.

(26) If the error involves a change in span, a calibration graph must be prepared. The graphical procedure outlined in (33) to (38) below is recommended because the barometric and background gas corrections are taken into account in a single process.

(27) If there is a scale shift larger than can be corrected as in (25) above, or if there is a span change larger than about 10 percent of the full scale, it is advisable to return the instrument to the factory for repair and recalibration (see (46) below). However, preparation of a calibration graph may permit the analyzer to be used until it can be spared for repairs.

Correction for Background-Gas Effect

(28) As was previously explained, the Beckman oxygen analyzer measures the magnetic effect produced by the gas sample in the analysis cell. What is measured is actually the difference between the paramagnetic effect of the oxygen tending to rotate the test body in one direction and the slight diamagnetic effect of the other gas tending to rotate it in the opposite direction. Each analyzer is calibrated so that its scale will give correct readings with a particular background gas. If the actual sample contains a background gas with a different amount of diamagnetic effect, the readings will be in error. Because nitrogen is much more strongly diamagnetic than helium, helium-oxygen analyses with an instrument calibrated for nitrogen will be incorrect, and vice versa.

(29) The amount of error is actually rather small. The difference in readings around 20 percent oxygen is about 0.2 percent. (It is smaller at higher percentages of oxygen because there is less background gas present.) Even though it is small, the difference should not be ignored because it might combine with other sources of error to produce a serious inaccuracy. However, it is not necessary to calculate an exact correction except in precise work. The following instructions should be used to correct readings:

(*a*) When a helium-oxygen mixture is analyzed with an instrument calibrated for nitrogen-oxygen, subtract the percent of error from the scale reading.

Scale reading, percent:	*Percent to subtract from scale reading*
0–15	0.3
15–50	.2
50–85	.1
85–100	0

(*b*) When a nitrogen-oxygen mixture is analyzed with an instrument calibrated for helium-oxygen, add the same factors to the scale reading.

Barometric Pressure Correction

(30) If the calibration of the instrument is correct and the factor for background gas has been added or subtracted if needed, the scale reading must still be corrected for barometric pressure unless the pressure at the time of analysis is within a very few millimeters of 760 mm Hg. The following formula can be used:

$$P=R\times\frac{760}{B}$$

where

P=corrected (true) percentage.

R=Beckman reading (assuming that calibration is correct and that background gas correction has been made if needed).

B=barometric pressure in mm Hg at time of analysis.

NOTE.—Barometric pressure can be expressed in inches of mercury if 29.9 is substituted for 760.

A table or graph of correction factors for various percentages and pressures can be prepared using this formula.

Summary of Corrections

(31) The various corrections that may be needed to adjust a Beckman scale reading to true oxygen percentage are—

(*a*) Correction for calibration errors, if any.

(*b*) Correction for the background-gas factor (if analysis involves a gas other than that for which the instrument was calibrated).

(*c*) Correction for barometric pressure other than 760 mm Hg at the time of analysis.

(32) For example, a mixture of helium and oxygen is analyzed with an instrument calibrated for nitrogen-oxygen. The barometric pressure is 775 mm Hg and the scale reading is 20 percent.

(*a*) The calibration of the instrument was previously checked. The reading was found to be 0.5 percent high at 20 percent. The reading should, therefore, have been 19.5 percent.

(*b*) According to (29) (*a*) above, 0.2 percent must be subtracted because of the background-gas effect. This yields a value of 19.3 percent.

(*c*) The barometric pressure correction called for by (31) above is found to yield

$$P=19.3\times\frac{760}{775}=19.3\times0.98=18.9 \text{ percent}$$

Therefore, the actual oxygen percentage is only 18.9 percent. Although all of the corrections are small, in this case (not unusual) they add up to more than 1 percent—a serious error in many situations.

Graphical Method of Correction

(33) If many analyses have to be done, the work of going through two or three steps of correction for each analysis can accumulate over a period of time. Almost all this work can be avoided by preparing a graph that takes all of the corrections into account and that can be used without calculations. Such a graph is based mainly on the data that must be obtained in the essential process of checking the analyzer's calibration. The calculations required in making the graph amount to less work than that required in correcting one or two individual analyses by the discussed methods. Directions for constructing correction graphs are given in the following paragraphs.

General Description

(34) A correction graph has a horizontal scale representing actual Beckman readings and a vertical scale representing true oxygen percentages. It also has several lines running diagonally across the graph from the lower left to the upper right. These are labeled with different barometric pressures. To use the graph, the operator locates (on the horizontal scale) the Beckman reading produced by the sample he is analyzing. The reading is followed up the graph to the point where it crosses the diagonal line for the existing barometric pressure. The point is then followed to the left to see where it lies on the true percentage (vertical) scale. This single operation takes into account any calibration error of the instrument as well as the corrections for background gas and barometric pressure. A sample correction graph is shown in figure B–5. (Note that a different graph must be prepared for each instrument.)

Instructions

(35) To prepare a calibration graph for helium-oxygen analysis with a 0- to 25-percent Beckman Model C analyzer, these steps must be followed:

(*a*) Review sections (20) to (24) above for basic calibration procedure.

(*b*) Obtain a large sheet of graph paper and a long ruler.

(*c*) Label the bottom edge (horizontal scale) of the graph paper "Beckman Reading" and mark it off from minus 1 or 2 percent to plus 25 percent.

(*d*) Label the left side of the paper (vertical scale) "True Percent Oxygen in Helium," and mark it off from zero to 25 percent.

(*e*) With the instrument fully warmed up, run pure helium from a fresh cylinder through the analyzer at the proper rate. Run it long enough to secure complete flushing of all tubing and corrections and of the sample cell. Note and record the reading. Repeat to assure complete washout.

(*f*) Find the line on the Beckman-reading scale of the graph that corresponds to the reading. Make a small dot where this line crosses the zero line of the true-percent scale.

(*g*) Run fresh air through a drying tube into the analyzer. (This can be done by attaching a piece of tubing to one of the nipples on the instrument and applying mild suction to draw the air through.) Make the reading and record it. Repeat the process several times to make sure washout is complete and to verify the reading.

(*h*) Find the line on the Beckman-reading scale that corresponds to this reading and make a mark. Then follow this line up to the point that corresponds to 20.7 percent on the true-percent scale and make a small dot.

NOTE

The air is known to contain 20.94 percent oxygen, but it is also known that because of the different diamagnetic effects of nitrogen and helium, 20.7 percent oxygen in helium would give the same Beckman reading as air.

(*i*) If a line were now drawn between the two points on the graph, it would indicate the correct relationship between any Beckman reading and the corresponding true percentage of oxygen in helium at the existing barometric pressure. However, the graph will be less cluttered and more useful if lines are drawn only for even steps through the probable range of barometric pressures. Lines for the following pressures are suggested if the barometer is marked in millimeters:

Millimeters Hg
740
750
760
770
780
790

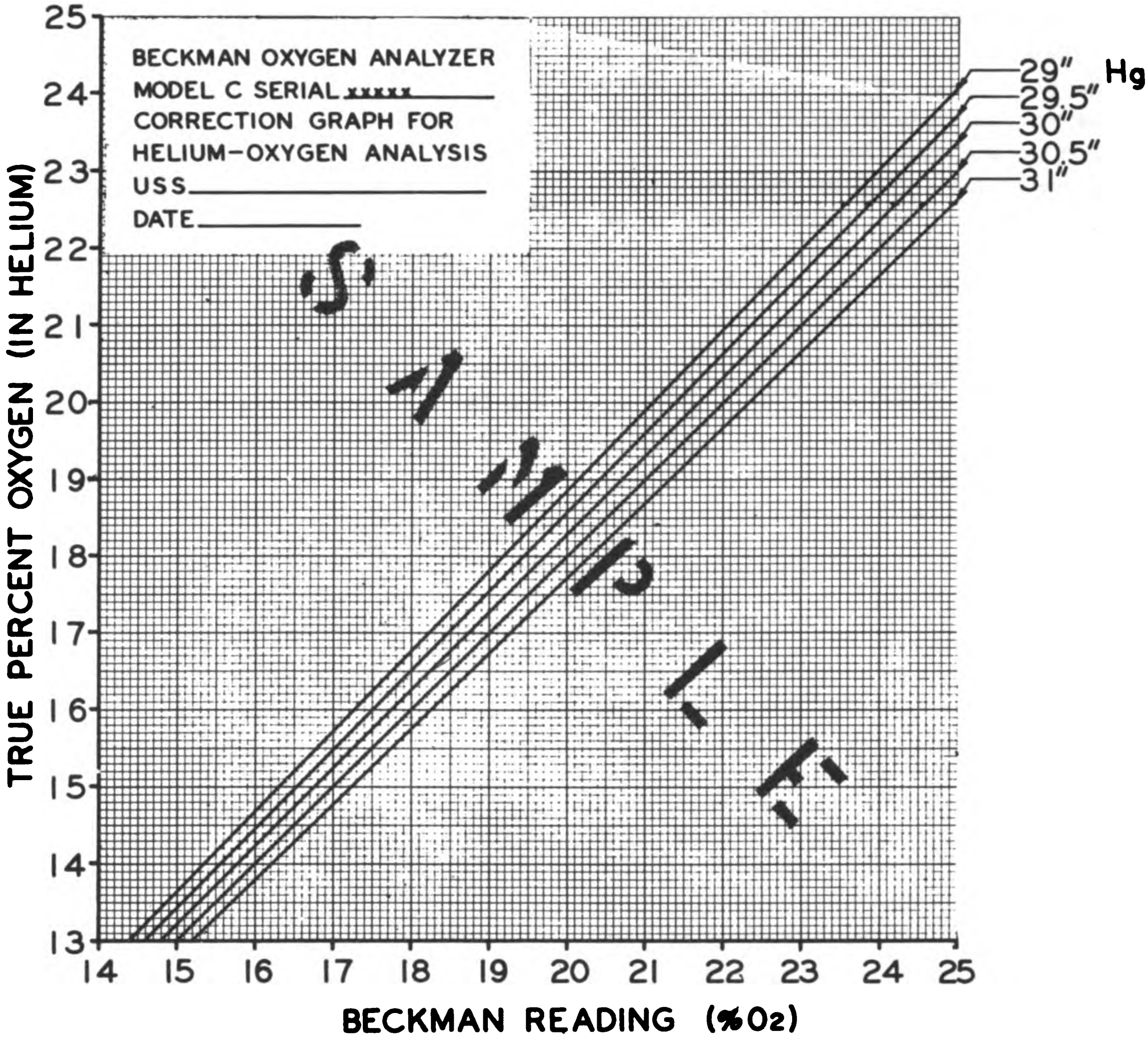

FIGURE B–5.—Sample correction graph for Beckman oxygen analyzer.

If the barometer is marked in inches, draw lines for the following pressures:

Inches Hg
29.0
29.5
30.0
30.5
31.0

(*j*) If the existing barometric pressure happens to correspond to one of the values, take a sharp pencil and very accurately draw a distinct line between the zero and air points and extend it up to about 25 percent on the reading scale. Label this line with the barometric pressure it represents. If the barometric pressure is something other than one of those values, draw only a light line along the ruler, extending it about 2 percent above and below the air point.

(*k*) To obtain the additional points needed for drawing the indicated barometric pressure lines, this procedure must be followed:

1. A reference percent for a barometric pressure of 29.5 in. Hg (750 mm Hg) can be calculated by using this formula:

$$\text{Reference percent} = 20.7 \times \frac{29.5 \text{ (or 750)}}{\text{Existing barometric pressure}}$$

2. Find the reference percent on the true-percent scale and follow it over to the diagonal line you have drawn. Make a dot at the point where it meets the diagonal and draw a straight vertical line lightly through the dot.

3. Follow this vertical line to the point where it corresponds to 20.7 percent on the true-percent scale and make another dot. Carefully draw a line through this dot and the zero point extending it to about 25 percent. Label the line 29.5 in. Hg or 750 mm Hg.

4. Return to the vertical line you drew in step (*b*) and place dots where it crosses the following true percents so you can draw diagonals representing the corresponding barometric pressures:

True percent:	*Barometric pressure, in. Hg*
21.1	29.0
20.7	[1] 29.5
20.4	30.0
20.0	30.5
19.7	31.0
or	
	mm Hg
21.0	740
20.7	[1] 750
20.4	760
20.2	770
19.9	780
19.7	790

[1] Already drawn.

5. Draw lines carefully through these points and the zero point, extending the lines to about 25 percent and labeling them. This completes the correction graph.

(*l*) To make the graph easier to use accurately, the portion covering the percentage range being dealt with can be enlarged. For example, if mixtures with concentrations below 15 percent are not to be analyzed, a large graph of the 15- to 25-percent portion can be made. To do this, very carefully read the points where the barometric pressure lines cross the graph lines representing true percentages of 15 and 25 percent and replot them on the spreadout scales of the new graph. (Fig. B-5 is a sample of such an enlargement.)

(*m*) In using the graph, read from the barometric pressure line closest to the actual barometer reading. Interpolation between the lines increases the accuracy, but it is seldom essential.

(36) The procedure for making a similar correction graph for nitrogen-oxygen mixtures is almost identical, but there are some differences:

(*a*) Use pure nitrogen instead of pure helium for the zero point. (If pure helium is the only oxygen-free gas available, it can be used; but plot the zero point at plus 0.3 percent instead of zero on the true-percent scale.)

(*b*) Plot the initial air point at 20.9 percent on the true-percent scale instead of 20.7 percent as when calibrating for helium.

(*c*) In finding the points for drawing the various barometric pressure lines, use the same procedure as in (35)(*k*) above; but use 20.9 percent instead of 20.7 percent, and add 0.2 percent to each of the true percents given in (35)(*k*)(4) above.

(37) In making a correction graph for an instrument with a 10- to 25-percent scale, a carefully analyzed mixture containing slightly over 10 percent oxygen must be used as the low point, just as was discussed under the topic of calibration in (22) above. The mixture with the background gas for which the instrument is to be used must be made up. Separate points must be plotted at the 10-percent-plus level to permit corrective barometric pressure lines to be drawn. This procedure must be followed after obtaining readings for the 10-percent-plus mixture and air:

(*a*) Plot points for air at different barometric pressures as described in paragraph (35)(*k*).

(*b*) Draw a straight, vertical line lightly at the point on the horizontal scale that corresponds to the Beckman reading for the 10-percent-plus mixture.

(*c*) Determine the barometric pressure.

(*d*) Multiply the barometric pressure by the true oxygen percentage of the calibration mixture. This yields the partial pressure of oxygen of the Beckman reading.

(*e*) Now determine what true percentages of oxygen would yield the same oxygen partial pressure (and thus the same reading) at the different barometric pressures. To do this, simply divide the partial pressure determined above by the needed barometric pressure.

(*f*) Plot points on the vertical line where it crosses the true percentages found in (*e*) above.

(*g*) Carefully draw a line through the air and the 10-percent-plus points for each barometric pressure line.

(38) To use the correction graph, these steps must be followed:

(*a*) Run the sample through the analyzer according to proper analysis procedure (see (16) and (17) above).

(*b*) Record the reading obtained.

(*c*) Determine the barometric pressure.

(*d*) Find the Beckman reading on the horizontal scale of the graph.

(*e*) Follow it up to the barometric pressure line closest to the actual barometric pressure.

(*f*) From the point where it crosses this line, follow the Beckman reading left to the vertical scale and read off the true percentage of oxygen in the mixture.

(39) For example (refer to fig. B–5), the Beckman analyzer gives a reading of 20 percent for a helium-oxygen mixture. The barometric pressure is 30.5 in. Hg. The true percentage, corrected for the instrument's calibration error, the background-gas effect, and barometric pressure, is 18 percent.

(40) Once a correction graph has been constructed, it can be used as long as the calibration of the instrument remains the same. To assure accuracy, it is necessary to check the calibration periodically whether a graph is used or not. The graph simplifies this process. To check the air point, for example, air is run through the instrument as done during the original calibration check. The reading is recorded and the graph is used to obtain the true percentage. If the calibration is still the same, a value very close to 20.9 percent or 20.7 percent will be given, depending on whether the graph was made for nitrogen-oxygen or helium-oxygen mixtures.

Maintenance

(41) If the relatively few possible causes of damage are avoided (see (14) and (15) above), the Beckman oxygen analyzer requires little maintenance effort.

(*a*) Calibration (see (18) above) should be checked at least once a day when in operation and after each time the analyzer is moved any distance or is unintentionally jarred. It is most desirable to check at least an air reading every time a series of analyses is to be run. Adjustments should be made or a correction graph remade if required.

(42) If no light beam appears on scale when the instrument is turned on, possible causes should be considered and ruled out in this order:

(*a*) Power failure or poor cord connection. (Ruled out if pilot light glows.)

(*b*) Beam thrown off the scale by sample beyond instrument's range. (Flush with air.)

(*c*) Analyzer lamp burned out. (Remove cover and hold white card in front of suspension housing. If no spot of light is seen on card, lamp is not operating.)

(*d*) Test body or suspension broken, or mirror fouled or desilvered by moisture or corrosive gas. (Hold instrument so test body can be seen; give instrument slight rotary twist. Test body should swing freely; mirror should appear shiny.)

(43) In order to replace the analyzer lamp (Mazda PR–2), the cover should be removed. The aluminum mirrors inside must not be touched. The spring contact must be carefully lifted and the old bulb removed. The new lamp should be placed in the socket. If necessary, the spring contact should be slightly bent to assure necessary tension to hold the lamp in place. Lamp should be rotated until a good image is formed on the scale. Calibration should be rechecked. If off, the bulb should be rotated further; otherwise only the lamp arm, etc., should be adjusted (see (25) above).

(44) If anything is wrong with the test body, suspension, or mirror, the instrument should be returned to the manufacturer for repair and recalibration (see (46) below).

(45) If pilot light fails to glow when instrument is first turned on and occasionally after warmup, the heater is failing to operate and all analyses will be in error. The pilot light (Mazda No. 44) must be checked. Relay contacts should be cleaned by drawing a clean sheet of paper between the contacts while holding them closed with finger. Loose connections should be checked. If trouble is not corrected, the instrument should be returned for repairs.

Moving and Shipment

(46) If the Beckman oxygen analyzer is to be moved any distance or shipped, it should be replaced in the original shipping box if this is available. In any case, it must be surrounded by

about 6 inches of shock absorbent packing in a carton. If being returned to the factory, the analyzer must be shipped by prepaid express and with appropriate correspondence. Purchase-order number assigned to cover repairs must be indicated. The name of the activity dealing with the instrument must be included. The following address may be used: Beckman Instruments, Inc., 2400 Harbor Boulevard, Fullerton, Calif. 92634.

B–E. BECKMAN MODEL D OXYGEN ANALYZER

(1) As figure B–4 indicates, the Model D Beckman instrument is much smaller than the Model C. The basic principle is exactly the same, but there are several important differences in construction and operation:

(*a*) The Model D is battery operated. The indicating light beam appears only when the button on the top of the case is pressed.

(*b*) There is no heater, so the readings will vary with temperature as well as with barometric pressure.

(*c*) It is not designed for continuous-flow sampling, and the test body is not protected against the excessive flow rates of a sample. It should be used only with the sampling bulb and tubes provided.

(*d*) A drying tube of indicator silica gel is provided to dry the gas samples. The gel must be changed as soon as much of the color has changed from blue to pink.)

(*e*) Most of the Model D's in use have a 0- to 100-percent scale, usually marked in oxygen partial pressure as well as percent.

(*f*) Because the scale is much smaller than that of the Model C, less accuracy is possible in making readings. The manufacturer claims an accuracy of plus or minus 2 percent of the full scale at [illegible]° F. With proper attention to calibration and corrections, better accuracy than this is possible; but without attention to these details, the results can be seriously misleading.

Operation

(2) Sampling of the gas must be accomplished with the rubber-bulb-tube system provided, never by connecting the analyzer to a cylinder. If gas from a cylinder is to be sampled, one of the best methods is to run gas from the cylinder into a small rubber bag or balloon with an open end. The sampling tube should be then inserted into the bag. The gas should be run from the cylinder fast enough to keep the bag [illegible] and [illegible] so fast that it will be pressurized. Then the bulb should be used to draw the sample through the analyzer. In some situations, it is convenient to place a hypodermic needle (15 gage or so) on the sampling-tube adapter. The needle can be inserted through the wall of a mask, tube, or rubber bladder with little damage. (The needle must be open; and the connections between the needle, the adapter, and the tube should not leak.)

(3) Follow these general steps:

(*a*) Place end of sampling tube at point from which sample is desired (see (2) above).

(*b*) Slowly squeeze and release aspirator bulb at least four times to insure complete removal of previous sample.

(*c*) Press light-switch button on top of instrument.

(*d*) When light beam stops moving, read oxygen percentage or partial pressure from position of beam on graduated scale. (Determine by calibration procedure which edge of the beam gives the most accurate reading and always read the same edge.)

Calibration

(4) Calibration of the instrument can be checked by the same procedures described for the Model C (see app. B [illegible]). Because of the smaller scale [illegible] readings, the background gas factor can be ignored. However, the barometric pressure must be considered [illegible] and an additional correction should be made for temperature [illegible] at the time of [illegible] calibration [illegible] much must be [illegible] significant [illegible]

about 6 inches of shock absorbent packing in a carton. If being returned to the factory, the analyzer must be shipped by prepaid express and with appropriate correspondence. Purchase-order number assigned to cover repairs must be indicated. The name of the activity dealing with the instrument must be included. The following address may be used: Beckman Instruments, Inc., 2400 Harbor Boulevard, Fullerton, Calif. 92634.

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(1) As figure B–4 indicates, the Model D Beckman instrument is much smaller than the Model C. The basic principle is exactly the same, but there are several important differences in construction and operation:

(*a*) The Model D is battery operated. The indicating light beam appears only when the button on the top of the case is pressed.

(*b*) There is no heater, so the readings will vary with temperature as well as with barometric pressure.

(*c*) It is not designed for continuous-flow sampling, and the test body is not protected against the excessive flow rates of a sample. It should be used only with the sampling bulb and tubes provided.

(*d*) A drying tube of indicator silica gel is provided to dry the gas samples. (The gel must be changed as soon as much of the color has changed from blue to pink.)

(*e*) Most of the Model D's in use have a 0- to 100-percent scale, usually marked in oxygen partial pressure as well as percent.

(*f*) Because the scale is much smaller than that of the Model C, less accuracy is possible in making readings. (The manufacturer claims an accuracy of plus or minus 2 percent of the full scale at 75° F. With proper attention to calibration and corrections, better accuracy than this is possible; but without attention to these details, the results can be seriously misleading.)

Operation

(2) Sampling of the gas must be accomplished with the bulb-and-tube system provided, never by connecting the analyzer to a cylinder. If gas from a cylinder is to be sampled, one of the best methods is to run gas from the cylinder into a small rubber bag or balloon with an open end. The sampling tube should be well inserted into the bag. The gas should be run from the cylinder fast enough to keep the bag flushed and filled but not so fast that it will be pressurized. Then the bulb should be used to draw the sample through the analyzer. In some situations, it is convenient to place a hypodermic needle (18 gage or so) on the sampling-tube adapter. The needle can be inserted through the wall of a mask, tube, or rubber bladder with little damage. (The needle must be open; and the connections between the needle, the adapter, and the tube should not leak.)

(3) Follow these general steps:

(*a*) Place end of sampling tube at point from which sample is desired (see (2) above).

(*b*) Slowly squeeze and release aspirator bulb at least four times to insure complete removal of previous sample.

(*c*) Press light-switch button on top of instrument.

(*d*) When light beam stops oscillating, read oxygen percentage or partial pressure from position of beam on graduated scale. (Determine by calibration procedure which edge of the beam gives the more accurate reading and always read the same edge.)

Calibration

(4) Calibration of the instrument can be checked by the same procedure described for the Model C (see app. B–D(20)). Because of the smaller scale and consequently less precise readings, the background-gas factor can be neglected. However, the barometric pressure must be considered in calibration, and an additional correction should be made for temperature if it is not between 70° and 80° F at the time of calibration (see (6) below). Adjustment of the instrument to correct calibration errors is not very satisfactory with the Model D, so it is generally better to compensate for a scale-shift error by making a note of how much must be added or subtracted. If there is a significant span error, construction of a calibration correction graph along the lines of that described for

the Model C is recommended (see app. B–D (33)).

Corrections

(5) Barometric pressure corrections can be made by using the formula given for the Model C analyzer (see app. B–D(30)). Assuming that the instrument is properly calibrated, the partial pressure reading is correct at any barometric pressure and can be converted to true percent oxygen by dividing it by the existing barometric pressure in mm Hg.

(6) Temperature corrections are not essential when analyses are performed at temperatures between 65° and 85° F (18° to 30° C), but they should be made beyond this range for reasonable accuracy. (High temperature can cause falsely low readings, and vice versa.)

(*a*) Use one of these factors for accurate correction:

$$P=\frac{R\times(460+°\text{F})}{535} \qquad \text{(Fahrenheit)}$$

$$P=\frac{R\times(273+°\text{C})}{297} \qquad \text{(centigrade)}$$

where

P=percent corrected for temperature
R=Beckman reading, corrected for calibration error and barometric pressure, if necessary.
°F or °C=temperature at time of analysis.

(*b*) For rough corrections, the following rules and factors can be employed:

For each 10° above 75° F, add the amount of the factor to the reading. For each 10° below 75° F, subtract the amount of the factor from the reading. (If the temperature is 20° below 75° F, subtract the factor twice, etc.)

Reading:	*Factor*
0–15	0
15–35	.5
35–65	1.0
65–85	1.5
85–100	2.0

(*c*) Example of rough correction:

A reading of 50 percent is obtained when the temperature is 95° F. Because 95° F is 20° above 75° F, the factor 1.0 is added twice. This gives a corrected percentage of 52 percent.

Maintenance

(7) Precautions and maintenance of the Model D Beckman oxygen analyzer are much the same as for the Model C (see app. B–D(41)), although certain exceptions are obvious. Some of the matters that may require attention are—

(*a*) Replacement of the silica gel (see (1) (*d*) above): Be sure to renew the cotton packing in tube each time. (Silica gel can be regenerated by heating it to about 300° F.)

(*b*) Replacement of the batteries (standard size D flashlight cells): Remove cover and sponge rubber pads and stand instrument on its back, scale up. Rotate battery clips downward and outward to remove batteries. Note that one is inverted in respect to the other. Insert new batteries, hold them in position with thumbs, and rotate clips back into position. Press light switch to check operation. Replace sponge rubber pads and cover.

(*c*) Replacement of the lamp (standard Mazda prefocused flashlight bulb PR–2): Remove batteries as in (*b*). Slide the square knurled clip back and downward to release contact spring and bulb. Put in new bulb and replace the batteries. Rotate bulb until a satisfactory beam on scale is obtained. If beam remains unsatisfactory, try another bulb.

(*d*) Replacement of the rubber aspirator bulb: Note that the check valve is positioned so that gas is drawn rather than pushed through analyzer. Reverse check valve in replacement bulb if necessary.

(8) Return instrument to manufacturer for any repairs involving the test body, mirror, or the suspension, or for correction of large calibration errors (see app. B–D(46)).

B–F. CARBON DIOXIDE ANALYSIS

(1) In diving, analysis of gas for carbon dioxide may be desired for two main reasons:

(*a*) To check for CO_2 as a contaminant in compressed air and gas mixtures for breathing.

(*b*) To determine the CO_2 levels in closed- and semi-closed-circuit scuba.

(2) Carbon dioxide is an unlikely contaminant in compressed air and in gases acquired from reliable commercial sources, but it can be present in air from compressors used in the field. Small concentrations could cause trouble in deep diving. For example, 1 percent CO_2 breathed at 132 feet would have the same effect as 5 percent CO_2 breathed at the surface. Sufficiently accurate analysis for amounts of CO_2 in this range requires an infrared-type analyzer. Analyzers like those discussed in (3) below would be useful in detecting the presence of a gross amount of CO_2 (over 1 or 2 percent). They should be used if the presence of CO_2 is suspected and a more precise analyzer is not available.

(3) Reasonably accurate analysis for larger concentrations of carbon dioxide can be accomplished with several types of analyzers manufactured for such purposes as analyzing flue gases. The one of this type most commonly found in the Navy is the Dwyer CO_2 analyzer. One of these is carried aboard every submarine. It is a simply operated chemical analyzer, and, if properly maintained, it will give sufficiently accurate results in the range for which it is intended.

(4) Attempting to analyze a gas from the breathing bag of a closed- or semi-closed-circuit scuba has several possible pitfalls. Such an analysis might be desired, for example, in a case of unexplained loss of consciousness in the use of such rig. However, unless a sample can be obtained immediately, the absorbent (even if almost completely exhausted) will produce a considerable reduction in the concentration of carbon dioxide in the system. Sampling from the breathing bag (inspiratory side if it is a split bag) while the rig is being used by a working subject is more likely to produce meaningful results when questions of this sort arise.

B–G. CARBON MONOXIDE ANALYSIS

(1) Detection of this gas as a contaminant in compressed air for breathing is the main reason for carbon monoxide analysis in diving. Because 10 parts per million (0.001 percent) has been specified as the maximum allowable concentration, a sensitive method of analysis is required.

(2) A small portable carbon monoxide tester that is simple to operate, sufficiently sensitive, and accurate is available in standard stock. It is rugged and can readily be carried along on diving operations. Analysis is accomplished by drawing the sample through a glass tube containing a chemical that changes color in the presence of carbon monoxide. The color produced indicates the concentration of carbon monoxide, and a built-in color scale is provided. The sample is drawn through the tube by means of a rubber bulb, and the sensitivity of analysis depends on the number of times the bulb is squeezed. If the smallest color change shown by the scale is produced with five squeezes of the bulb, this indicates 0.001 percent CO—the maximum limit for CO content in air to be used in diving. If this same color develops after two squeezes, the concentration is over the limit.

(3) The tester is designed for direct sampling from room air, so a modification must be employed for testing air from cylinders. It is recommended that a short nipple be tightly attached to the normal intake hole, with care being taken not to interfere with the sealing arrangement at the end of the glass tube. (An accessory of this kind can be obtained.) One possible method of sampling would be to attach the nipple securely to the hub of a large hypodermic needle. The needle could then be inserted into a rubber tube or bag kept flushed with the gas in question during the sampling period.

(4) The detailed instructions that accompany the analyzer should be read and carefully followed. An ample supply of indicating tubes must be maintained.

B–H. PURITY STANDARDS FOR COMPRESSED GASES

Oxygen

(1) Oxygen is covered by Federal Specification BB–O–925. Three grades of type I (gaseous) oxygen are—

Grade A: Aviator's breathing.
Grade B: Industrial and medical.
Grade C: Technical.

(2) Grades A and B, differing only in moisture content, must both contain not less than 99.5 percent oxygen and pass the tests specified by the *U.S. Pharmacopeia* (XIV Revision). Aviator's breathing (grade A) oxygen must be extremely dry to avoid the possibility of moisture freezing in valves or lines with consequent stoppage of flow at low temperatures at high altitude. The amount of moisture in grade B oxygen (not more than 5 ml of free water per cylinder is specified) rarely presents a problem in diving, so this grade is generally satisfactory. Technical (grade C) oxygen is not suitable for breathing. To prevent mixups, diving ships and activities should, if possible, avoid having it aboard for any purpose.

(3) The tests specified by the *U.S. Pharmacopeia* are for acidity or alkalinity, carbon dioxide, other oxidizing substances, halogens, and carbon monoxide.

(4) Activities using oxygen should return cylinders with the valve closed and with a residual pressure of not less than 25 psi. They must avoid damaging or contaminating the cylinders.

Nitrogen

(5) Federal Specification BB–N–411a (1955) and Military Specification MIL–N–6011 (1950) are concerned with nitrogen. Both specifications include oil-free and non-oil-free types. Only oil-free nitrogen is suitable for use in diving. The Federal specification describes three grades of type I (gaseous), class 1 (oil-free) nitrogen:

Grade A: 99.95 percent pure, maximum moisture content 0.02 mg per liter.

Grade B: 99.5 percent pure, maximum moisture content 0.02 mg per liter.

Grade C: 99.5 percent pure, not more than 5 ml of free water per cylinder.

(6) Moisture content of compressed gases is rarely critical in diving, and 99.5 percent purity is satisfactory, provided that the remainder consists of oxygen with no more than a trace of carbon dioxide and with no other contaminants. Class 1, grade C nitrogen should generally be satisfactory for use in preparing breathing mixtures. However, the specifications evidently do not take into consideration the use of nitrogen for breathing, and tests for various possible trace contaminants are not specified as they are for oxygen. In obtaining nitrogen for use in making up breathing mixtures, supplier should be informed of the intended use and consulted concerning the possibility of harmful substances in the grades available. Care exercised in preparing and filling cylinders will sometimes vary with the grade and thus may also influence the choice. Where there is doubt concerning the presence of contaminants, some of the tests described for oxygen in the *Pharmacopeia* (2) may be applied by a qualified laboratory.

Helium

(7) Helium is produced by the Federal Government. Four grades—A, B, C, and D—are listed, but only grades A and D are currently being produced. Grade A helium is approximately 99.999 percent pure and is free of oil and moisture. Grade D is of similar purity except that it is oil pumped and therefore unsuitable for the preparation of breathing mixtures. (Grades B and C, if again produced according to existing specifications, would both presumably be suitable for use in diving.)

Compressed Air

(8) Comparable specifications and purity standards for high-pressure compressed air for

breathing have not yet been established. The following are considered as maximum standards for compressed air to be used with surface-supplied air diving or when charging open-circuit *scuba* cylinders:

Oxygen concentration: 20 to 22 percent by volume.

Carbon dioxide: not more than 0.05 percent (500 ppm).

Carbon monoxide: not more than 0.002 percent (20 ppm).

Oil vapor: not more than 5 mg/m^3.

Gross moisture, dust, or other foreign matter: must be free of these.

(9) Almost all high-pressure air available aboard ships or in field activities is pumped by oil-lubricated compressors and may contain harmful contaminants. Contamination with oil vapor may be heavy, and unacceptable amounts of carbon monoxide may be present. Some oil vapor will be present in the output of any oil-lubricated compressor. Wear and inadequate maintenance will increase the amount. Contamination with carbon monoxide (and in some cases carbon dioxide as well) can arise from two main sources:

(*a*) The gas may be present in the intake air from having the intake too close to (or downwind from) the exhaust of a gasoline-driven compressor or other source of exhaust gas. (In some ships, the compressor draws air from a compartment that may be contaminated with carbon monoxide or carbon dioxide.)

(*b*) Some, or perhaps all, oil-lubricated compressors, if not carefully operated, can develop cylinder temperatures that cause partial combustion of the lubricating oil. Products of combustion can consequently be formed within the compressor itself.

(10) Filtering systems are the only means of dealing with contaminants when the output of an unsatisfactory compressor must be used. Studies are being conducted with the aim of producing optimal detailed specifications for filter systems. Materials such as activated alumina or other appropriate substances that remove carbon monoxide and carbon dioxide must be used, often in combination, depending upon the contaminants concerned. The system must also prevent carryover of dust or particles from the absorbents employed. Care must be exercised to be sure that the materials are renewed or regenerated at appropriate intervals. Even with a good filter system, it is unsafe to mix oxygen with air from an oil-lubricated compressor.

(11) Where the source is not satisfactory beyond all doubt, air samples must be submitted at intervals to a suitable laboratory for analysis. There is no simple, reliable method for analyzing air for oil vapor in the field, but checks for carbon monoxide can be obtained with the instrument described above (see app. B-G). Sufficiently accurate analysis for small concentrations of carbon dioxide requires the use of an infrared-type analyzer, but gross contamination can be detected with a simpler apparatus described (see app. B-F).

(12) Despite the lack of formal standards, most manufacturers of compressed gases can supply water-pumped air of satisfactory purity and will do so if air for breathing is specified. (Specifying the intended use is important since some concerns also supply a lower grade of compressed air for commercial purposes. This may be oil pumped, contain various contaminants, or be sold in cylinders inadequately cleaned and evacuated.)

(13) Where the requirement for compressed air under high pressure does not involve great quantities and where the source is not too distant, the use of extra-large cylinders of commercial compressed breathing air in a cascade system may be the most satisfactory solution. A cascade system involves the use of three or more cylinders manifolded together. The cylinder being charged is filled first from the large cylinder having the lowest pressure, next from that with somewhat higher pressure, and finally topped off from that having the highest pressure. When the pressure in the latter becomes too low for topping off, the lowest cylinder is replaced with a full one which is then used for topping off. Very little air is wasted with such a system. Many smaller cylinders can be charged close to their capacity with it. Periodic renewal of one large cylinder is much easier than taking many scuba cylinders to the source.

B-I. CLEANING OXYGEN SYSTEMS

(1) Many diving ships and activities have, or may consider installing, a system by which oxygen is piped from a central bank to the recompression chamber, the diving station, or a charging board. Smaller systems such as manifolds are in common use. The necessity for avoiding all possible contact between high-pressure oxygen and oily materials has been stressed repeatedly in this manual because of the risk of explosion and fire. Any kind of system used with oxygen must be cleaned thoroughly upon installation, kept clean, and recleaned whenever there is known or possible contamination (such as allowing compressed air from an oil-lubricated compressor to enter a system).

(2) An example of an oxygen system being contaminated as the result of improper cleaning procedure was once provided by a manufacturer who supposedly cleaned the oxygen and high-pressure fittings of a scuba unit with a highly flammable solvent and left a considerable residue of this material in the system. Only the alert intelligence of a diver kept the unit from being charged with oxygen—an operation that would almost certainly have caused an explosion resulting in several deaths and much damage. NAVSHIPS' approved method, MIL STD 1330 (Ships), for cleaning shipboard oxygen-distribution systems, if followed carefully, will safely remove all foreign matter.

(3) The term "cleaned for oxygen service" means that all dirt, filings, grease, oil, and other foreign materials have been removed from all parts of the equipment and piping to be used in oxygen service. Equipment received from a manufacturer, such as cylinders and valves, that has been cleaned for oxygen service and that has all connections sealed when delivered need not be recleaned. If the systems are received with unsealed connections, they should be cleaned according to the method described here.

(4) Mixed-gas piping systems shall be cleaned in the same manner and maintained to the same standards as oxygen systems.

Materials Needed

(5) Materials needed for cleaning are—

(*a*) Degreasing solution: Trisodium phosphate (Na_3PO_4), anhydrous, technical grade, Fed. Spec. O-S-642, type I, FSN C 6810-664-7487 or trisodium phosphate ($Na_3PO_4 \cdot 12 H_2O$), dodecahydrate, technical grade, Fed. Spec. O-S-642, type II, FSN G 8610-240-2115 and G 8610-240-2116 and nonionic detergent. STK No. FSN 7930-282-9699 MIL-D-16791E type I.

(*b*) Fresh water, oil-free, filtered.

(*c*) Flushing solvent: Freon PCA less than 1 ppm total organic content.

(*d*) Gaseous nitrogen (water-pumped).

(*e*) Steam or other source of heat for the cleaning solution and rinse water.

(*f*) Rubber gloves, safety goggles, rubber boots and aprons, or other protective clothing to be worn while cleaning.

(*g*) Portable cleaning machine consisting of 55-gallon tanks connected to a Gould Co. ½-horsepower bronze centrifugal pump (or equivalent) with a capacity of 15 gpm at 20 psi.

(6) The cleaning solvent should be prepared by dissolving 65 pounds of technical-grade anhydrous trisodium phosphate or 145 pounds of technical-grade dodecahydrate trisodium phosphate to each 100 gallons of water with 1 pint of nonionic detergent. The mixture should be heated to 190° F ± 20° F with a steam coil or other source in 55-gallon drums.

Cleaning Procedure

(7) The cleaning procedure is as follows:

(*a*) All parts, including fittings, piping, valves, and so on, must be completely disassembled and washed before final assembly.

(*b*) The cleaning solution should be prepared as described in the preceding paragraph.

(*c*) Small parts should be placed in the cleaning bath and soaked for at least 10 minutes. Agitate the solution, or scrub with a brush, until all visible traces of dirt or grease disappear.

(*d*) Prior to cleaning, piping subassemblies containing valves shall have the valve internals removed. During valve reassembly, after cleaning the piping, valve internals are cleaned with Freon PCA and then blown dry using oil-free nitrogen.

(*e*) Circulate cleaning solvent prepared as indicated in (6) above with the circulating pump for 15 minutes.

(*f*) Rinse thoroughly with running, oil-free water. Drain off excess water.

(*g*) Fill system with Freon PCA flushing solvent. Allow the system to soak for 1 hour at ambient temperature and pressure. Pressurize system with oil-free nitrogen and blow down solvent to used solvent drum at each exit point.

1. If the discharge shows evidence of foreign matter or discoloration, repeat the fill and blowdown.

2. Obtain a 2-liter sample from each exit point in a clear glass container for analysis.

(*h*) Obtain laboratory analysis of the samples. If the analysis indicates 5 ppm or less total organic content, the piping is to be considered clean. If more than 5 ppm total organics are present, flushing is repeated until 5 ppm, or less, total organics in the solvent are obtained.

(*i*) Purge piping using oil-free nitrogen to remove all the solvent.

(8) The indicating, recording, and controlling equipment, or other small or delicate equipment should be cleaned with O_2 system cleaner MIL SPEC. MIL–C–8638, Stock No. RN 6850–597–7166–G500.

Special Precautions

(9) Trisodium phosphate solutions and O_2 system cleaner are harmful to the eyes and skin. If contact occurs, the area should be flushed with copious quantities of water.

(10) Only materials approved for use with oxygen for pipe dope, gaskets, etc., should be employed in reassembling oxygen systems.

(11) When systems have been cleaned, extreme care must be taken to prevent oil or any other combustible material from entering.

B–J. CALIBRATION OF GAGES

(1) Serious difficulties in diving can arise from the use of inaccurate gages. This is particularly true with gages employed to determine depth pressure, as on a recompression chamber or pneumofathometer. A relatively small error could result in improper decompression of a diver.

(2) All gages must be checked at least once every 12 months in accordance with NAVSHIPS Technical Manual, chapter 87–14, unless a malfunction requires repair or calibration more frequently.

(3) When the oxygen systems are being cleaned, as described in appendix B–I, gage lines should be removed and cleaned separately, after first cleaning the system with them attached. This is done to insure that the gage lines are thoroughly flushed. All gages must be removed from the system prior to the cleaning process to avoid dead ends in the system, and to avoid damage to the gage due to the heated detergent solution.

Calibration of Sea-Water Depth Gages

(4) Gage readings in depth, feet of sea water, are especially important in diving. Since almost all gage testers are graduated in pounds per square inch, conversions are needed. It is helpful to make up a conversion table in appropriate increments, giving pounds per square inch in one column and the corresponding depths in another.

(5) An appropriate number of points should be checked depending on the scale of the gage and the increments available with the tester. For example—

(*a*) If the gage scale is in 1-foot increments, check 10-psi increments of pressure to obtain readings for 22½, 45, 67½, 90, etc., feet.

(*b*) If the gage is marked off in 2-foot or 5-foot increments, 20-psi steps of pressure (45, 90, 135 feet, etc.) should be sufficient.

(6) At each increment of pressure, the actual reading of the gage being tested should be recorded, together with the true depth that corresponds to the pressure.

(7) In testing a gage, it is desirable to run more than one test (or at least to note readings both with increasing and decreasing steps of pressure) to check the consistency of errors. A gage that shows large or variable errors, or one that sticks excessively, should be turned over for repairs or surveyed.

(8) An attempt may be made to adjust a gage according to article 87–17 of the NAVSHIPS Technical Manual. If this is not done or is not wholly successful, a calibration curve (graph) or table must be prepared to indicate the relationship between true depths and gage readings. If the deviations are within 5 feet of true depth and vary less than 2 feet in a 50-foot change of depth, 50-foot increments must be used in the calibration table. If the deviations are greater than this, 10-foot increments must be used. (In such a case, readjustment, repair, or replacement of the gage is actually preferable.)

DEPTH GAGE #2

True depth	*Gage reads*
0	0
50	49
100	98
150	148
200	199
250	250
300	301
350	352
400	402½
450	453

USS PENGUIN

FIGURE B–6.—Sample table, depth gage calibration.

(9) The calibration table should be affixed to the inside of the gage face glass. It should resemble the sample in figure B–6 and should include this information:

(*a*) Identification of depth gage.
(*b*) True depths in feet.
(*c*) Corresponding actual gage readings.
(*d*) Name of ship or activity.
(*e*) Initials of individual responsible.
(*f*) Date of calibration.

(10) In using a gage with such a table, some interpolation is necessary. For example, the gage whose calibration table is shown in figure B–6 could be expected to read about 275½ for a true depth of 275 feet, or to indicate a true depth of about 323½ when it reads 325 feet. For most purposes, such estimates are close enough. A calibration graph, with true depth on one axis and actual reading on the other, would permit more exact and more rapid corrections.

B–K. AIR COMPRESSORS

HEAVY-DUTY AIR COMPRESSOR

(1) The air compressors furnished with the deep-sea diving outfits are the heavy-duty portable units designed to operate for long periods of time with maximum reliability. The units have a rated capacity of 55 cfm with an operating pressure of 100 psi. These compressors are furnished to activities having an allowance of deep-sea diving equipment that are called upon to undertake extensive diving operations: repair ships, tenders, salvage vessels, tugs, and other activities as approved by NAVSHIPS.

(2) There are at the present time two makes of heavy-duty compressors being issued with the deep-sea outfit. The unit shown in figures B–7 and B–8 is a four-cylinder engine with two single-stage compressor cylinders in a one-piece en bloc cylinder construction, with a crankshaft common to both the engine and the compressor. The crankcase, although in one piece, is divided and sealed between the engine and the air compressor to prevent any engine fumes and gases from entering the compressor system and contaminating the breathing air. This unit has an overall length of 83 inches, a width of 23 inches, a height of 52 inches, and a total weight of 1,800 pounds.

(3) A mechanical flyball-type governor is located on the outside of the timing gear cover and is connected to an auxiliary butterfly valve for limiting the maximum engine speed. The slowdown assembly, connected to the throttle-body butterfly, controls the acceleration and deceleration of the engine in relation to the loading and unloading of the compressor cylinders. This unit has a water-cooling system consisting of a large capacity radiator, centrifugal water pump, thermostat, and fan. The cooling system

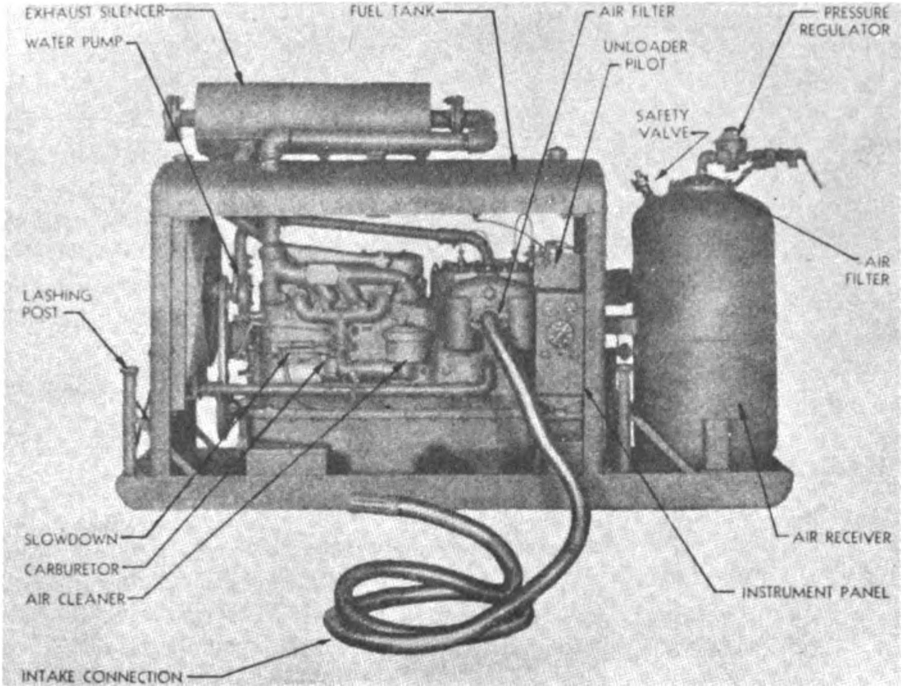

Figure B–7.—Air compressor 60 G1, carburetor side.

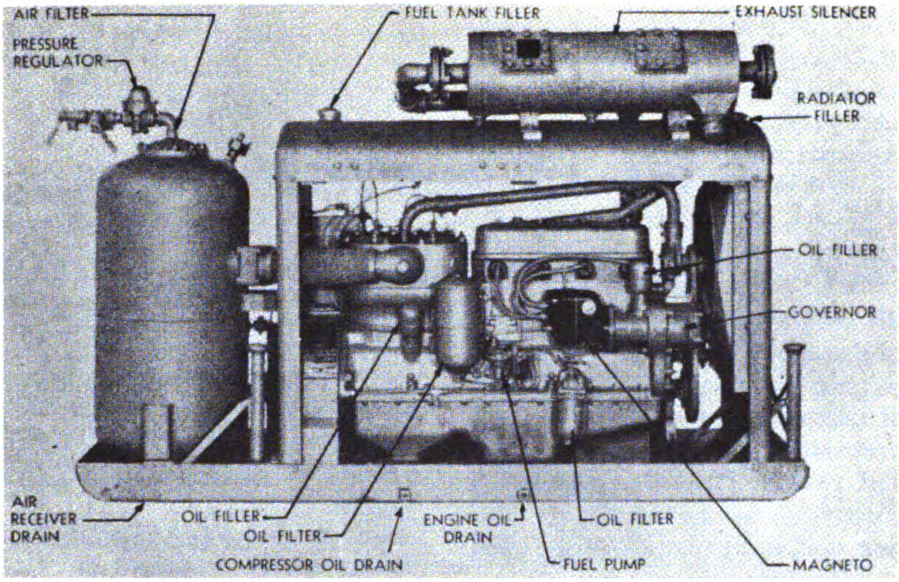

Figure B–8.—Air compressor 60 G1, magneto side.

is designed so that the compressor will operate satisfactorily at ambient temperatures ranging up to 140° F. An air receiver having a volumetric capacity of 5 cubic feet with a working pressure of 125 psi is mounted in a vertical position and is contained within the limits of the frame. The receiver is connected to the discharge ports of the compressor cylinder head by a flexible metallic connection.

(4) The second unit (see figs. B–9 and B–10) consists of a 4-cylinder, 4-cycle, V-engine that develops 23 horsepower at 2,200 rpm (full load). The engine is connected by multiple V-belts to a two-cylinder single-stage air com-

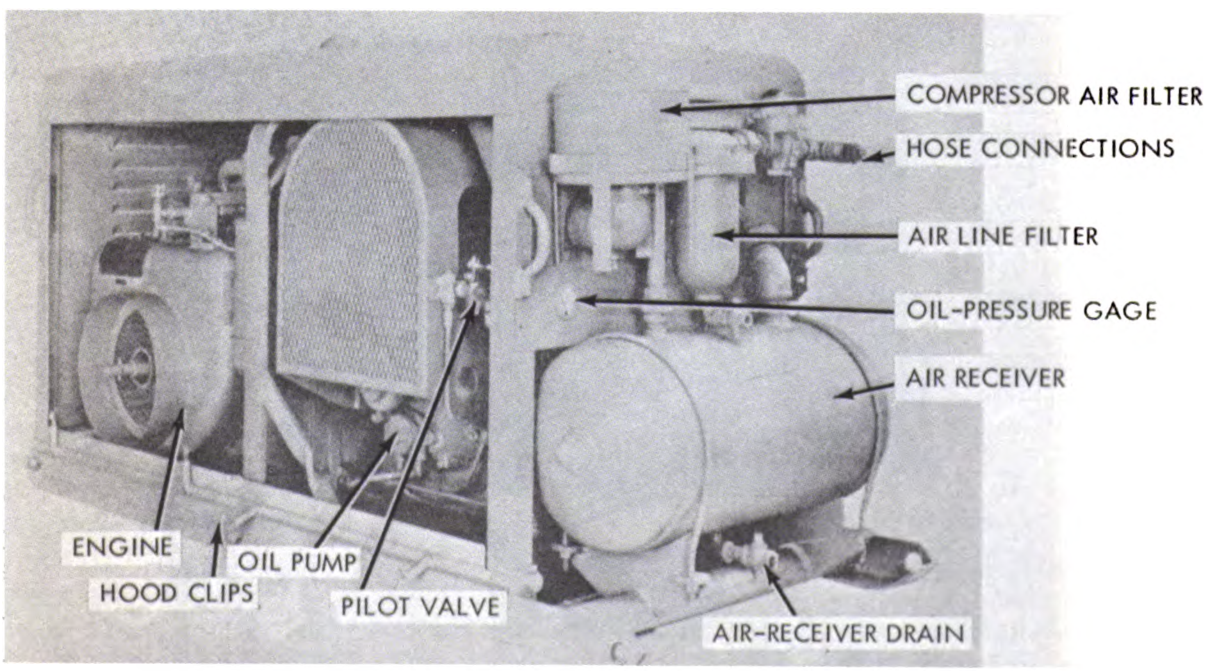

Figure B–9.—Right side of air-compressor unit (side covers removed).

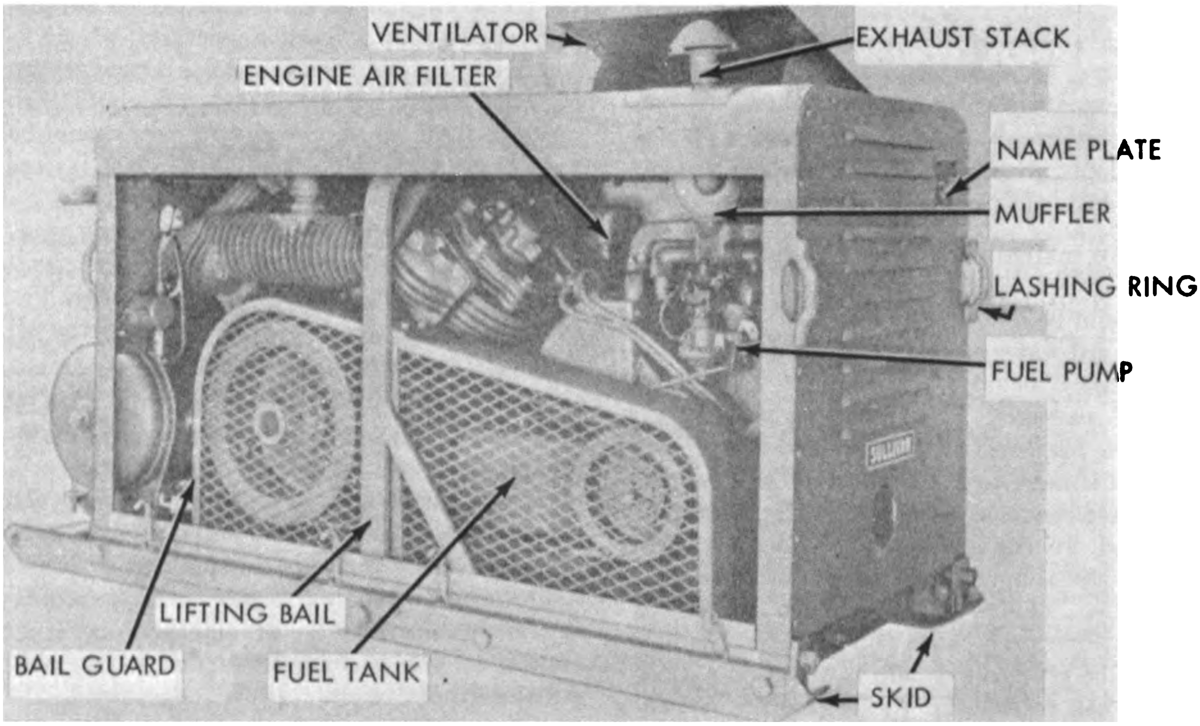

FIGURE B–10.—Left side of air-compressor unit (side covers removed).

pressor. The unit has an overall length of 70 inches, a width of 32 inches, a height of 37 inches, and a weight of 1,750 pounds.

(5) The compressor control regulator consists of a mechanical pilot valve, delay valve, engine throttle control, and cylinder unloader. A governor automatically regulates the engine speed by controlling the throttle valve of the carburetor. When the load on the engine decreases, the governor closes the throttle valve and does not let the engine operate beyond its maximum rated speed. Both the engine and compressor are air cooled. An air receiver having a 1.69-cubic-foot capacity at an operating pressure of 125 psi is located at the compressor end of the unit and acts as a storage tank and pulsation chamber.

Air Purification

(6) To insure that air of adequate purity within reasonable limits of pressure variation is furnished, several special pieces of equipment are supplied with the compressor. To prevent the breathing air from being contaminated with the engine exhaust fumes, both compressor models are furnished with a flexible metallic pipe extension approximately 15 feet long which connects to the compressor intake. The compressed breathing air is exhausted into a volume tank where, as a result of expansion, it is cooled and some of the oil and moisture are eliminated. There is a tendency in all oil-lubricated compressors for the compressed air to pick up a quantity of lubricating oil and vapor and to carry them through the diver's air hose. In order to prevent this condition, the air is passed from the receiver through an oil filter where the oil vapors are removed from the air.

(7) It is essential that the oil filter be kept in first-class condition, otherwise the breathing air will become contaminated with oil and become noxious to the diver. In addition to the contamination of the breathing air, oil in the air will accelerate deterioration of the diver's hose.

Maintenance of Compressors

(8) The compressor, one of the most vital items of the diving equipment, must be maintained in first-class operating condition at all times. In order to maintain maximum efficiency,

compressors and all air filtration units should be thoroughly checked and overhauled after each 200 hours of use. This routine preventive maintenance will often result in the correction of potential troubles before they have a chance to develop.

Cooling

(9) To maintain the water-cooled compressor in efficient operating condition, the radiators should be filled with clean soft water. The use of hard water should be avoided because of the tendency for scale to form in the water jackets and passages. Radiator hose connections should be inspected at the time of draining and replaced if necessary. When using the compressor in cold climates, adequate antifreeze should be added. In the event that the engine overheats, water should not be poured into the cooling system. This is because sudden changes in temperatures may cause the cylinder head to crack. The radiators should be filled only after boiling has ceased and the engine has cooled. Then the water should be slowly added. The air-cooled units depend for cooling upon air being forced over the large exposed area of the compressor, engine cylinder head, and cylinder fins. For adequate heat dissipation, the cylinder head and cylinder cooling fins must be kept free from foreign material to make sure that there are no obstructions in the engine shrouding or air-intake grill to hamper air circulation. This is essential when using the unit in hot weather conditions.

Lubrication

(10) One of the important considerations in the maintenance of the compressor is proper lubrication. After stowage, the oil in the compressor should be drained, and oil of proper viscosity for the prevailing climatic conditions should be placed in the engine and compressor. Castor oil or Navy Symbol 2190T should be used as the lubricant. During the time that the unit is in use, the quantity of oil in the crankcase should be kept at the FULL mark on the dipstick. If necessary, the oil supply in the engine and compressor should be checked daily and replenished as required. However, overfilling should be avoided because it may permit the connecting rods to dip into the oil supply, thus causing an excessive quantity of oil to splash on the cylinder walls. Smoking, oil pumping, and excessive carbon deposits could then result. All oil containers and funnels should be kept clean and well covered when not in use. It is essential that oil pans be drained and refilled with new oil regularly, because oil gradually accumulates small particles of dust, grit, and metal, which cause unnecessary wear. The oil pans should be drained only when the oil is hot.

Operating Precautions

(11) In addition to the above general maintenance problems, there are a number of precautions that should be taken while using the compressor units. When the compressor is in use, personnel assigned to the compressor should have duties primarily concerned with maintaining the compressor in satisfactory operating condition. The personnel assigned to the compressor should be responsible for removing the unit from stowage and preparing it for use—removing protective covers, checking, adding proper lubrication and gasoline, starting the unit, and insuring that there is no contamination of breathing air, and that the unit is running smoothly. Any indications that the unit is not running smoothly or any indication of failure should be reported immediately to the diving officer. The diver should then be brought to the surface in a manner determined by decompression requirements and the status of the dive. The compressor should be run until it is warmed up and running smoothly before any attempt is made to put a diver over the side.

(12) The compressor should never be operated in an unventilated room. However, when a unit must be operated indoors, a pipe should be run from the engine exhaust to the outside atmosphere. Whether the unit is operated indoors or outside, it should never be covered so that the engine exhaust fumes are thrown onto the compressor intake. The compressors are equipped with lashing rings or posts for securing in position. The units operate satisfactorily when tipped 15 degrees in any direction, but it is preferable that they be operated on a horizontal plane whenever possible.

Stowage Maintenance

(13) Diving operations are not conducted continuously, but rather intermittently, which causes the equipment to sometimes stand idle for long periods of time. Therefore, the problem of stowage maintenance must be given careful consideration. The compressor should be stowed in a dry, protected place. If the unit is to be stowed for a period of 30 days or more, the following general precautions should be taken.

(14) The engine and compressor crankcases should be drained and refilled with a light engine oil plus an antirust additive. The engine should be allowed to run for a few minutes to permit the oil to reach all passages. Because gasoline contains gums which separate and adhere to the various valves and passages, sometimes causing serious trouble, the entire fuel system should be drained. The spark plugs should be removed and a few ounces of antirust oil should be poured into each cylinder. The engine should then be turned over a few times with the crank to work oil down around the piston rings. Every entrance to the unit—exhaust pipes, cylinder head, breather, oil filler, carburetor, oil filters—should be carefully sealed to prevent the entrance of moisture. In the case of the water-cooled compressor, the cooling system should be drained, flushed, and refilled with fresh, clean, soft water and antifreeze if required.

(15) When removing the unit from stowage, the preparations listed in (11) above must be performed. The compressor should then be run a sufficient length of time to insure that it is operating normally before any attempt is made to undertake diving operations.

LIGHTWEIGHT AIR COMPRESSOR

(16) The diver's lightweight air compressor is intended to be used by the many activities whose duties are not primarily concerned with diving but which may be called upon to undertake minor diving operations at infrequent intervals. This type of compressor is generally furnished to auxiliary vessels, landing craft, patrol craft, combatant vessels, and other miscellaneous vessels for undertaking minor diving jobs, such as inspection, searching, and clearing lines. In addition, the lightweight compressor is issued as supplementary equipment to repair ships, tenders, salvage vessels, and to do minor diving jobs away from the vessel. It must be clearly understood that the lightweight air compressor cannot be used as a substitute for the heavy-duty air compressors. The lightweight compressor should be used only on diving jobs where the diver can make a direct ascent to the surface in the event the compressor fails. The compressor should not be used for diving to greater depths than 130 feet, and the maximum length of time that the diver spends in the water shall be such that no decompression will be required.

Stowage of Lightweight Compressor

(17) Because the lightweight compressor is furnished to activities that will undertake very limited diving operations, the equipment will be subject to long periods of stowage. It is, therefore, important that the compressor be properly prepared for stowage. Prior to stowage the water should be removed from the air receiver by running the compressor with all outlets closed to build up the maximum allowable pressure, and then the draincock should be opened in the bottom of the receiver. Gasoline should be drained from the tank and the engine should be run until it stops. The spark plug should be removed and sufficient rust additive should be sprayed into the cylinder head and block to cover the cylinder walls and valve surfaces. The engine should be drained of oil when hot and refilled with a light engine oil plus an antirust additive.

When the engine is to be used, the light oil should be drained and the oil of proper viscosity, depending on temperature conditions, should be added. All exposed parts should be thoroughly dry before stowage. If the compressor and engine have been exposed to salt water or spray, they should be washed down with fresh water. All connections should be checked for tightness and every entrance to the unit sealed to prevent moisture from entering. The frame should be covered with canvas and stowed in a dry place. If the unit is stowed for more than 1 month, the compressor should be run and the above process should be repeated at the end of each 30 days.

Instruction Books

(18) Each compressor unit is furnished with a complete instruction book containing information on the operation, maintenance, stowage, and parts list of the engine, compressor, and accessories. The instruction book should be retained with the unit at all times, and personnel using the diver's air compressor should be completely familiar with the information in the instruction books.

B–L. OXYGEN-ELIMINATION SYSTEM

General

(1) The use of oxygen in recompression chambers either for treatment or for general use in surface decompression procedures increases the fire hazard because of the higher percentages of oxygen in the chamber. The most meticulous safety precautions are required to prevent fires from occurring in chambers when the oxygen percentage is higher than that of air. Even air under pressure can increase the fire hazard. High ventilation rates are required to keep the oxygen percentage in a chamber at a maximum of 25 percent. This presents serious problems because the sound generated can cause deafness in divers. If the oxygen breathed by the diver or patient can be eliminated to the outside of the chamber, the need for high ventilation rates is abolished. Such a system can be easily prepared and is shown in schematic form in figure B–11.

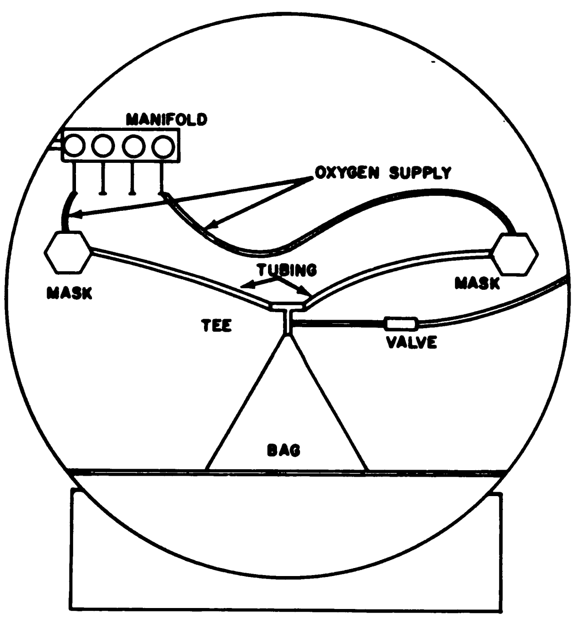

FIGURE B–11.—Oxygen-elimination system.

The Components of the System

(2) Figure B–11 shows the basic system as it would be arranged for two divers breathing oxygen. The components of the system are—

(*a*) A standard oxygen manifold.

(*b*) Standard demand-type oxygen masks modified so that the exhaust valves empty into the large tubing.

(*c*) Tubing of the wire braided type is 1⅛ inches internal diameter and leads from the exhaust valve to the T.

(*d*) The T-fitting is attached to the large hose and to the neck of the bag.

(*e*) The bag is a heavy-duty breathing bag which acts as a reservoir for the expired oxygen. It should be 100-liter size for two divers or 150-liter size for three divers. The neck of the bag or the T should be fitted for ¼-inch internal-diameter tubing.

(*f*) The small tubing is attached to a regulating valve and then led through a ¼-inch hull penetration.

Use of the System

(3) The mask in the normal-demand mode is used with care being taken to insure that a good face seal is made. Oxygen exhaled into the bag until it is about half full assures comfortable exhalation. When the bag is half full, the control valve on the small tubing is opened and adjusted by the divers to keep the bag about half full. As pressure is reduced, the valve must be opened farther to allow the reduced pressure differential to release oxygen from the bag to the atmosphere. The tubing sizes given are felt to be the minimum sizes compatible with low breathing resistance and adequate elimination of oxygen from the bag. Therefore, larger sizes of tubing may be used as needed or available.

U.S. NAVY DIVING MANUAL

APPENDIX C

TECHNICAL INFORMATION ON SURFACE-SUPPLIED DIVING

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CONTENTS

ILLUSTRATIONS

TABLES

C-A. DIVING OUTFITS

(1) There are three surface-supplied diving outfits in the U.S. Navy. They are the air hardhat, the helium-oxygen hardhat and the lightweight diving outfit.

Table C-1 lists components for the two hardhat outfits, No. 1 is for the air hardhat and No. 3 is for the He-O_2 hardhat. The No. 1 outfitting lists the components, quantities, and materials required for two divers, plus spare parts, to keep the outfits in repair for 1 year. The No. 3 outfitting is a special outfit issued to submarine-rescue vessels; this listing, in conjunction with table C-2 (special helium-oxygen diving outfit), is sufficient to conduct limited submarine personnel rescue and submarine salvage.

Table C-3 lists the requirements for two divers using the lightweight diving outfit and necessary spare parts.

These tables are meant as guidelines to determine the minimum amount of equipment necessary for diving with each type of equipment. The necessary equipment may be increased as the diving situations of the command dictate. In many cases, substitutions for such items as clothing must be made depending upon their availability through the normal supply channels.

TABLE C-1.—*Deep-sea diving outfit*

Item	Component	Unit	Outfit	
			No. 1 (air)	No. 3 (He-O_2)
1	Amplifier, complete (intercommunication set)	Number	1	3
2	Bag, diver's tools	Number	2	6
3	Belt, diver's weight	Number	2	8
4	Box, tool and spare parts	Number	1	2
5	Cable, assembly, combination amplifier and lifeline, 200 ft	Number	3	2
6	Cable, assembly, combination amplifier and lifeline, 600 ft	Number	----------	8
7	Cement, rubber	Quarts	2	12
8	Chest, helmet stowage	Number	1	----------
9	Chest, outfit stowage	Number	3	----------
10	Clamps, air hose	Number	12	12
11	Cloth, patching, diver's dress	Yards	2	4
12	Compressor, gas driven, 55 cfm	Number	1	1
13	Coupling, air hose, female	Number	2	6
14	Coupling, air hose, male	Number	2	6
15	Coupling, air hose, double female	Number	2	6
16	Coupling, air hose, double male	Number	2	6
17	Coupling, diving cable, telephone	Number	2	3
18	Cuffs, diver's dress, rubber	Pair	8	20
19	Cushion, diver's helmet	Number	2	6
20	Die, rethreading, ½ in.—12	Number	1	2
21	Die, rethreading, 1¹⁄₁₆ in.—17	Number	1	2
22	Drawers, 75 percent wool, size 36	Pair	6	4
23	Drawers, 75 percent wool, size 38	Pair	6	12
24	Drawers, 75 percent wool, size 40	Pair	6	8
25	Dress, diver's, size No. 1 (small)	Number	1	4
26	Dress, diver's, size No. 2 (medium)	Number	3	12

TABLE C–1.—*Deep-sea diving outfit*—Continued

Item	Component	Unit	Outfit	
			No. 1 (air)	No. 3 (He-O_2)
27	Dress, diver's, size No. 3 (large)	Number	2	4
28	Faceplate, clear, helmet	Number	1	4
29	Faceplate, welding, helmet	Number	1	
30	Filter, air	Number	1	1
31	Flag, B, alphabetic international	Number	1	
32	Flag, 4, numerical international	Number	1	
33	Gasket, faceplate	Number	2	6
34	Gasket, helmet, leather	Number	4	10
35	Glass, helmet, face window	Number	2	6
36	Glass, helmet, side window	Number	1	6
37	Glass, helmet, top window	Number	1	6
38	Gloves, diver's	Pair	8	24
39	Gloves, woolen	Pair	4	18
40	Glycerine, U.S.P	Pints	1	
41	Halyard, signal, cord, cotton	Feet	20	20
42	Helmet, deep-sea diver's	Number	2	7
43	Hose, assembly, air, high pressure, 3 ft	Lengths	3	12
44	Hose, assembly, air, high pressure, 3 ft 9 in	Lengths		4
45	Hose, assembly, air, high pressure, 50 ft	Lengths	12	68
46	Jackbox, amplifier	Number	3	10
47	Knife, diver's (with sheath belt and buckle)	Number	2	10
48	Ladder, diver's, iron	Number	1	1
49	Lead, weight, sounding, 7 lb	Number	1	
50	Lens, welding, faceplate, No. 4	Number	12	
51	Lens, welding, faceplate, No. 6	Number	3	
52	Lens, welding, faceplate, No. 8	Number	3	
53	Light, 200-ft cable, 100 watt	Number	1	
54	Light bulb, 1,000 watt	Number		6
55	Light, extension, 1,000 watt	Number		4
56	Line, descending, 200 ft	Lengths	2	
57	Line, distance, 60 ft	Lengths	3	
58	Line, sounding, ¼-in. cotton cord, 200 ft	Lengths	2	
59	Litharge	Pounds	2	
60	Manifold	Number	1	3
61	Manual, diving	Number	1	
62	Nut, wing, breastplate (large)	Number	4	15
63	Nut, wing, breastplate (small)	Number	8	30
64	Oil, neat's-foot	Quarts	2	
65	Packing, air control, flax	Feet	100	100
66	Reducer, air hose, type S	Number	4	18
67	Reducer, air hose, type T	Number	2	6
68	Safety latch, diver's helmet	Number	2	7
69	Screw, machine, brass 8–32 NC by ⅜ in	Gross	1	1
70	Sealing compound, beeswax for amplifier, gooseneck	Pounds	2	10
71	Shoes, diver's, light (26 lb)	Pair	1	3
72	Shoes, diver's, heavy (40 lb)	Pair	2	6
73	Socks, 75 percent wool, size 11	Pair	4	16
74	Socks, 75 percent wool, size 12	Pair	4	16
75	Socks, 75 percent wool, size 13	Pair	4	16
76	Springs, primary and secondary regulating escape valve	Pair	6	12
77	Stage, diver's, decompression, 1-man	Number	1	2
78	Stage, diver's decompression, 2-man	Number		1
79	Stopwatch	Number	1	1

TABLE C-1.—*Deep-sea diving outfit*—Continued

Item	Component	Unit	Outfit	
			No. 1 (air)	No. 3 (He-O_2)
80	Strap, cuff, diver's dress with buckle	Pair	2	4
81	Stud, breastplate (long)	Number	4	6
82	Stud, breastplate (long, short)	Number	8	18
83	Tap, rethreading, 1 1/16 in.—17 NS	Number	1	2
84	Tap, rethreading, 1/2 in.—12 N	Number	1	2
85	Trousers, overalls	Pair	3	9
86	Tubing, elastic	Yards	2	20
87	Undershirts, woolen (small), size 38	Number	6	6
88	Undershirts, woolen (medium), size 42	Number	6	12
89	Undershirts, woolen (large), size 44	Number	6	6
90	Valve, air control, angle	Number	2	12
91	Valve, air, nonreturn	Number	4	6
92	Valve, regulating, air escape (exhaust)	Number	2	6
93	Washer, amplifier	Number	20	50
94	Washer, copper, for breastplate straps	Number	12	50
95	Washer, nonreturn valve seat	Number	4	20
96	Weight, 50-lb	Number	1	12
97	Weight, 100-lb	Number	2	12
98	Wrench, for nonreturn valve	Number	1	4
99	Wrench, open end, for air hose	Number	2	6
100	Wrench, open end, for amplifier and lifeline coupling	Number	2	6
101	Wrench, spanner, for diving cable	Number	2	6
102	Wrench, T-slot, for diving helmet	Number	4	6

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TABLE C–2.—*Special helium-oxygen diving outfit*

Item	Unit	Quantity
Helmet, complete with breastplate, canister, injector, 3-ft 9-in. length of standard diver's air hose, control valve with adapter, and Hoke valve and recirculator supply hose.	Number	3
Helmet spares:		
Exhaust, valve, secondary, complete	Number	1
Valves, rubber	Number	6
Screws, for rubber valves	Number	6
Gaskets, for exhaust valve, secondary	Number	3
Hoke valve	Number	5
Injector spares:		
Nozzle, high pressure	Number	3
Nozzle, discharge, venturi	Number	3
No. 72 drill	Number	3
Pin vise for No. 72 drill	Number	1
Gas-mixing equipment:		
Tee for splitting gas flasks, ¼-in. high-pressure, equipped with 0- to 3,000-psi gage and 2 left-hand nuts to fit helium flasks.	Number	2
Tee for mixing gas, ¼-in. high-pressure, equipped with 0- to 3,000-psi gage, left-hand nut to fit helium flasks, and right-hand nut to fit oxygen flasks.	Number	2
Pump, oxygen transfer	Number	1
Oxygen, 200-cubic-foot flasks	Number	20
Helium, 200-cubic-foot flasks	Number	100
Gas analysis outfit:		
Beckman oxygen analyzer	Number	2
Lubriseal (stopcock grease)	Tubes	10
Mineral oil	Pints	1
Rubber tubing, 3/16 by 5/64 in	Feet	50
Rubber tubing, ¼ by 3/16 in	Feet	10
Gas collecting tubes	Number	6
Micrometric control valves, for bleeding sample from helium flask	Number	2
Baralyme, granular, in approximately 7-lb containers, 6 containers in box	Pounds	900

TABLE C–3.—*Lightweight diving outfit*

Item	Component	Unit	Quantity
1	Belt, cartridge, unmounted	Number	2
2	Belt, leather	Number	2
3	Cement, rubber	Quarts	1
4	Clamp, securing, diver's dress	Number	3
5	Cloth, patching, diver's dress	Yards	2
6	Compressor, gas driven, 15 cfm [1]	Number	1
7	Drawers, 75 percent wool, size 38	Pair	2
8	Drawers, 75 percent wool, size 40	Pair	2
9	Dress, diver's, light weight	Number	2
10	Dress, swimmer's, wet suit	Number	2
11	Filter, air	Number	1
12	Gasket, face dress	Number	4
13	Gloves, diver's	Pair	4
14	Gloves, woolen	Pair	4
15	Harness, head, mask	Number	2
16	Hose, assembly 50 ft	Lengths	4
17	Knife and sheath, diver's	Number	1
18	Mask, diver's	Number	2
19	Shoes, gymnasium, size 10	Pair	1
20	Shoes, gymnasium, size 12	Pair	1
21	Shoes, diver's, light (26-lb)	Pair	2
22	Socks, 75 percent wool, size 12	Pair	4
23	Trousers, diver's	Pair	2
24	Tubing, elastic	Yards	1
25	Undershirts, 75 percent wool, size 38	Number	2
26	Undershirts, 75 percent wool, size 42	Number	2
27	Valve, control, globe	Number	2
28	Valve, flapper, dress	Number	6
29	Valve, flapper, mask	Number	6
30	Valve, nonreturn	Number	3

[1] If shipboard air is not available.

C–B. EXHAUST VALVE

(1) The exhaust valve is one of the most important features of the diving helmet (fig. C–1). The principles of operation are as follows: The internal pressure in the diving helmet is normally maintained at about ½ psi in excess of the external water pressure. As the pressure builds up in the suit, it is exerted against the stem valve disk (*H*) which is closed against the air pressure by the primary spring (*K*). When the internal pressure is ½ psi in excess of the external pressure, the valve stem is unseated, and air is allowed to escape. The valve stem continues to move forward, increasing the exhaust opening until the valve stem adjusting sleeve (*J*) comes in contact with the secondary spring follower (*N*), one end of which fits into the secondary spring (*O*). This secondary spring is designed and constructed to maintain 2-psi internal pressure over the external pressure when the valve is fully closed, a condition which exists when the regulating screw (*F*) is screwed until the follower disk (*N*) bears directly against the valve-stem adjusting sleeve.

(2) The exhaust opening desired is obtained by regulating the distance that the valve stem travels before coming in contact with the secondary valve spring. This distance is controlled by the valve-stem adjusting sleeve (*J*) that screws on the valve stem (*B*). The sleeve's longitudinal travels in either direction to give the desired setting for length. When the proper setting is obtained, the sleeve is locked into place by the setscrew (*M*) which screws into a threaded hole in the end of the valve stem. The initial setting should be made so that the secondary valve-spring follower disk (*N*) comes

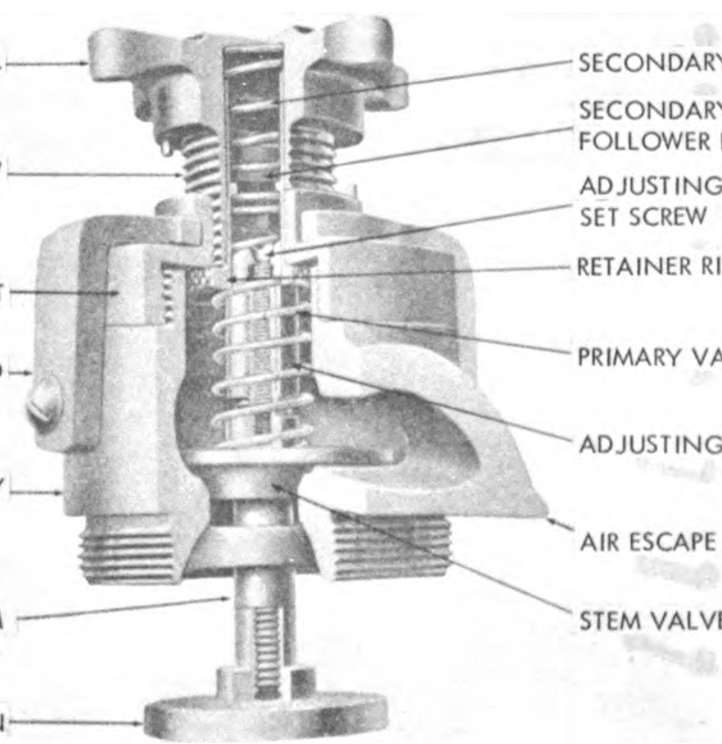

FIGURE C–1.—Air-regulating exhaust valve.

in contact with the sleeve when the adjusting wheel (*G*) is about one-eighth of a turn short of the fully closed position. The diver is then able to produce any desired airflow by manipulation of the handwheel. Regardless of the setting, it is always possible to obtain full opening immediately by manually depressing the chin button (*A*). This is because after the ½-psi spring is compressed until the setscrew (*M*) brings it up against the disk (*N*), the longitudinal motion of the valve stem may be continued to the maximum degree of travel by compression of the secondary spring (*O*). When the valve is fully opened, the shoulder on the underside of the chin button strikes the valve-stem guide, preventing the chin button from partly closing off the air passage with consequent restriction of the airflow.

(3) The regulating screw (*F*) is provided with a handwheel (*G*) of improved design which permits a diver wearing gloves to grasp the handwheel more easily and to estimate the degree of turn more readily than with wheels of conventional type. A dowel pin on the underside of the handwheel strikes against another dowel pin on the bonnet (*E*) when the valve is in the fully closed position, thus preventing the wheel from continuing its travel until it becomes jammed against the bonnet. The bonnet guard (*D*) prevents the bonnet from backing off the exhaust valve body (*C*).

C–C. WELDING FACEPLATE

(1) The welding faceplate is used in any instance where the diver would be exposed to excessive glare from the welding apparatus. The details of this faceplate are in figure C–2 which gives a technical description of its construction.

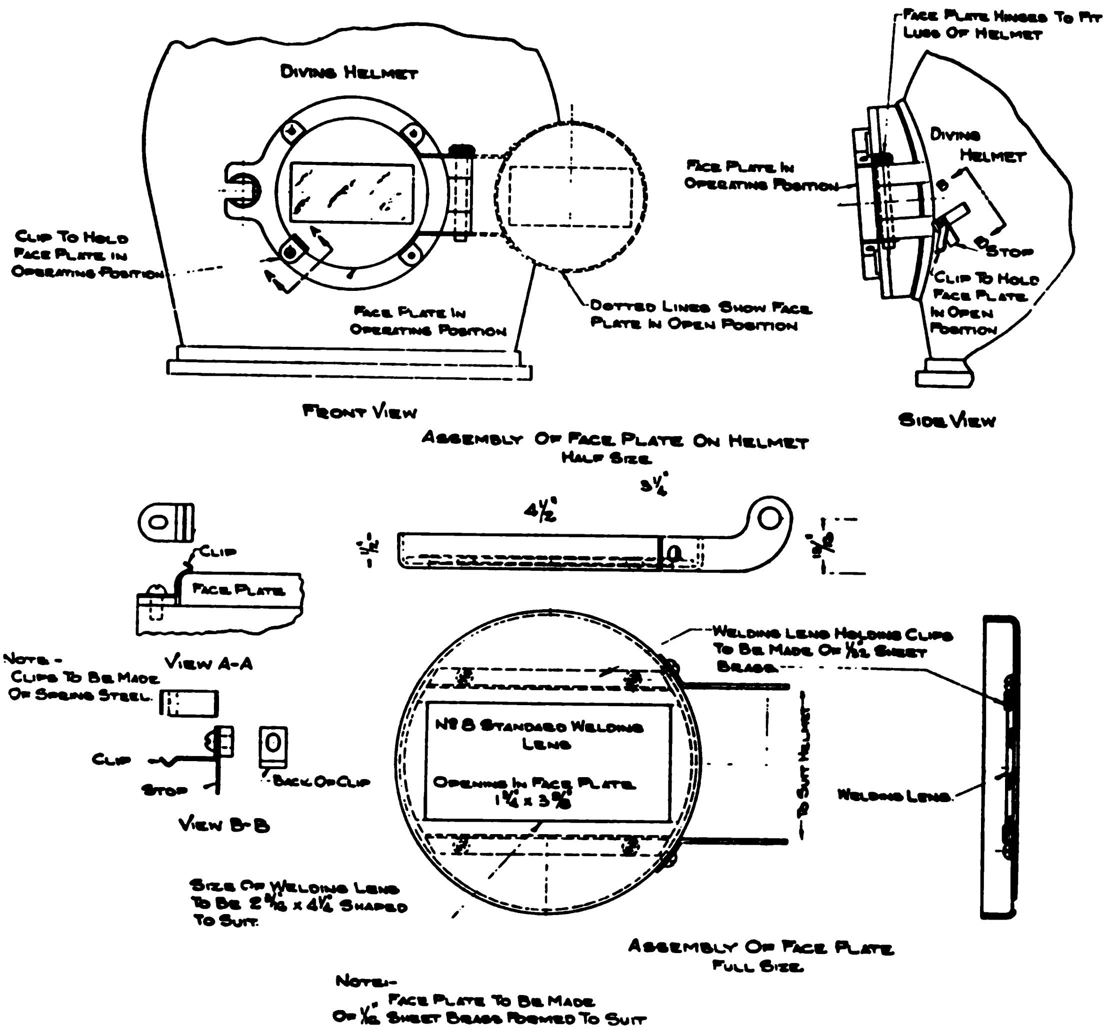

FIGURE C–2.—Welding faceplate.

C–D. PATCHING THE DIVING DRESS

(1) Any loose fabric or other material and old cement should be removed from the dress with benzine or trichloroethylene. These and most other solvents and cements are toxic and/or flammable in various degrees. Thus, their use should be restricted to well-ventilated spaces having an airflow to the outside atmosphere. Containers should be kept tightly sealed and stowed only in authorized spaces when not in use.

(2) The area should be roughed with sandpaper or a clean wire brush and cleaned with benzine or trichloroethylene.

(3) A piece of patching cloth of the desired size and shape should be cut with all corners being rounded.

(4) The protective cloth should be stripped from the patch and clamped flat to a board with the heads of thumbtacks so that the tacks do not pierce the patch.

(5) At least three coats of rubber cement should be applied to both the dress and patch, with each coat being allowed to dry until it is tacky before the succeeding coat is applied. The cement should be applied with a brush.

(6) When the last coat of cement is dry enough, the patch should be laid on the dress and pressed down firmly or tapped with a wooden mallet, being worked from center to edge, to remove all air bubbles and wrinkles.

(7) If any part of the edge of the patch does not adhere thoroughly and is inclined to curl, loose parts should be trimmed with sharp scissors.

(8) The dress should not be used, if possible, for 24 hours.

(9) Tears in the collars of diving dresses are usually confined to the vicinity of the stud bolt holes. Tears should be sewed together with herringbone stitches, the needle holes filled with cement and allowed to dry, after which a patch should be cemented around the damaged hole on each side of the collar.

C–E. ATTACHING CUFFS AND GLOVES TO DIVING DRESS

(1) The following method of attaching the cuff to the dress is recommended:

(*a*) Make a tapered wooden plug (see fig. C–3) that will fit tightly into the sleeve of the dress and extend past the sleeve edge about 4 inches.

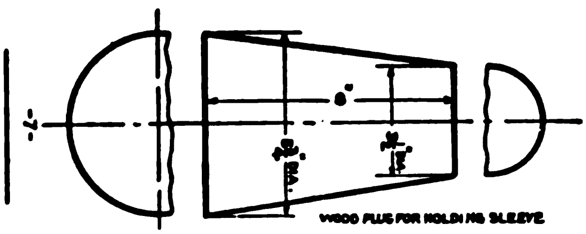

FIGURE C–3.—Wood plug.

(*b*) Roughen the outside of the sleeve edge about 3 inches from the edge with sandpaper.

(c) Turn the sleeve edge of the cuff back about 2½ inches and roughen it.

(*d*) Slip the cuff over the small end of the wooden plug until it touches the sleeve edge.

(*e*) Apply at least three coats of rubber cement to the sleeve and turned-back portion of the cuff, allowing each coat to dry until it is tacky (approximately 45 minutes) before applying the succeeding coats.

(*f*) Roll the turned-back part of the cuff up over the sleeve and press down firmly.

(*g*) Cut two curved strips of patching cloth in accordance with figure C–4(a). Roughen with sandpaper and apply three coats of cement in the same manner as the cuff and dress.

(*h*) Apply one strip evenly over the joint between the cuff and the sleeves.

(*i*) Turn the dress sleeve inside out and apply a strip between the cuff and the sleeve joint.

(*j*) The dress should not be used for 24 hours, if possible, to permit the rubber cement to dry thoroughly.

(2) In order to attach the divers-tenders gloves to the diving dress:

(*a*) Insert the wooden plug (see fig. C–3) into the sleeve of the dress.

(*b*) Loosen the lower part of the elbow patches and fold back.

(*c*) Cut 1 inch off the top (gauntlet) of the glove for attaching to a No. 3 dress, 2 inches off for attaching to a No. 2 dress, and 3 inches for attaching to a No. 1 dress.

(*d*) Turn back 2 or 3 inches of glove gauntlet and place glove over the sleeve plug until it touches the sleeve.

(*e*) Cut two strips of patching cloth as indicated on figure C–4(a).

(*f*) Prepare the surfaces of dress sleeve, gauntlet, and strip of patching cloth as indicated in the sections on dresses and cuffs.

(*g*) Have the glove thumb line up with the dress sleeve so that the glove will land in the natural position of the diver's hand.

(*h*) Roll the turned-back section of the glove in place over the prepared section of the dress.

(*i*) Place the patching strip in place.

(*j*) If time permits, allow the cement to dry for 24 hours.

(3) The repair of the glove is made similarly to the method of repairing the diving dress: The worn fabric should be removed from the glove and roughened with sandpaper. Patches for the glove should be cut according to the patterns shown in figure C–4 (b), (c), (d). The patches and glove should be prepared at the same time. When both are ready, an assistant should put on the glove and half close his hand to conform to the natural curvature of the glove. The thumb patch, figure C–4(d), is then applied, with care being taken to smooth out all wrinkles. Palm patches, figure C–4 (b), (c), are next applied if necessary, and the wrinkles smoothed out along the entire surface of the patch. The rough edges of the patches should be clipped off and the glove removed. The glove should be allowed to set, if possible, for 24 to 48 hours. Before stowing, the gloves should be washed with clean water and allowed to dry thoroughly.

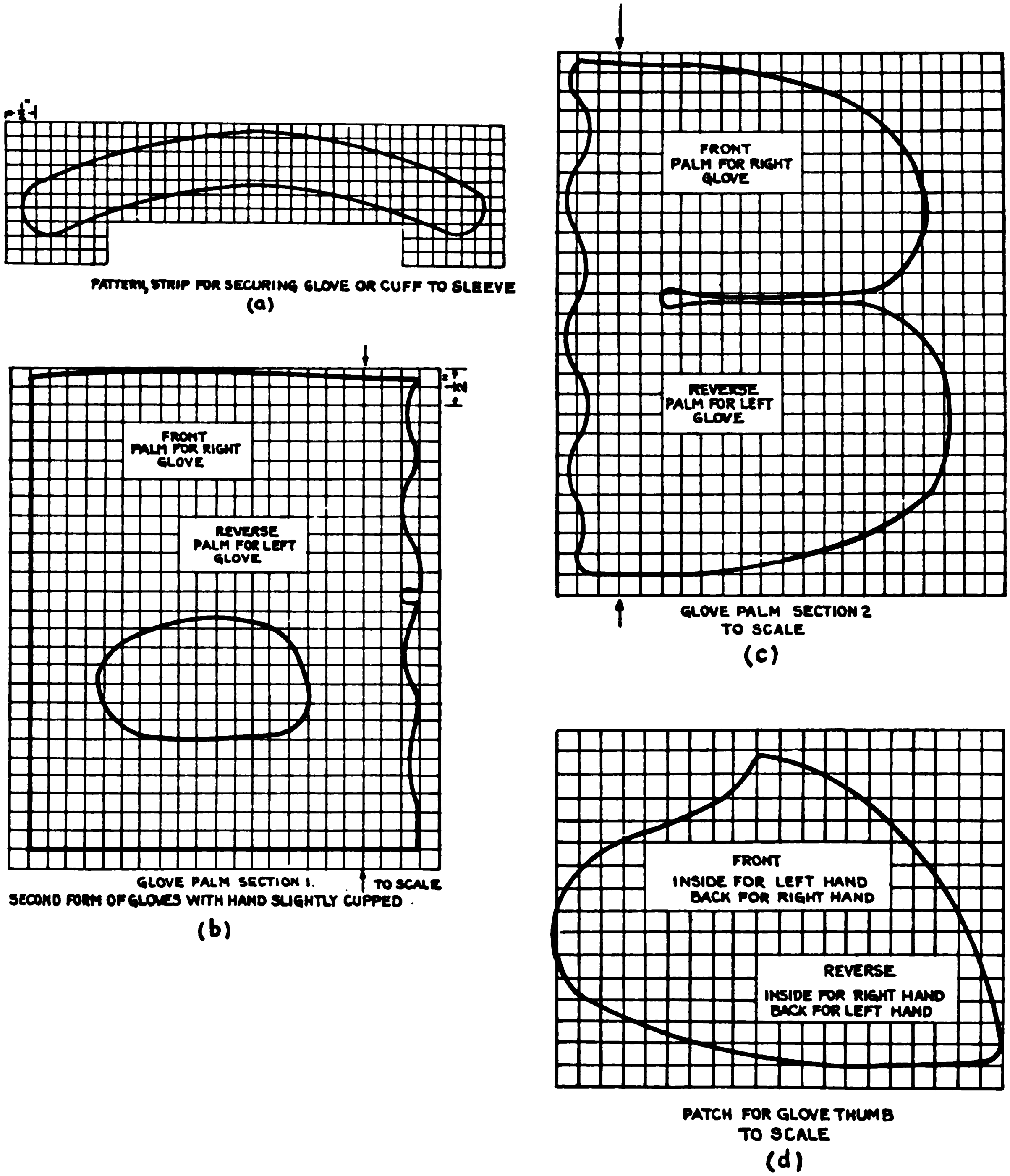

FIGURE C–4.—Glove patch patterns.

C–F. REPLACING LIGHTWEIGHT FACE GASKET

(1) The old strapping gasket and old cement should be removed from the dress with benzine, trichloroethylene, etc.

(2) The edges of suit hood where the old gasket was attached and the strapping for the new gasket should be lightly sandpapered.

(3) A thin film of rubber cement should be spread on each sanded surface and allowed to dry until tacky. This procedure should be repeated for two or three coats.

(4) As the last application of cement becomes tacky, the new gasket should be firmly pressed into position on the hood. If marks left by removal of old gasket are accurately followed, the fit will be perfect.

(5) The old binding tape (or facsimile cut from patching cloth) should be cemented over the seam. It should be allowed to dry overnight before being used.

C–G. DIVING INTERCOMMUNICATION SYSTEM

(1) The diving intercommunication system that has been adopted for standard use in the U.S. Navy consists of the following basic items:

(*a*) The diving amplifier.

(*b*) The diver's reproducer (loudspeaker).

(*c*) The combination diving amplifier and lifeline cable.

Several different models of diving intercommunication systems exist, but each works basically in the same manner.

Diving Amplifier

(2) The diving amplifier is portable and is placed in a convenient location on the tending vessel, barge, or pier. The combination diving amplifier and lifeline cable plugs into the amplifier and extends from the tender to the diver. The diver's reproducer is mounted in his helmet.

(3) Two models of diving amplifiers are now in general use. The following table will serve to identify each model:

Manufacturer	Manufacturing model number	I.C. instruction book number	Number of selector or keys
(*a*) Guided Radio Corp	957	82A (NAVSHIPS 3650220)	6
(*b*) Guided Radio Corp	H–919	82 (NAVSHIPS 3650288)	3

(4) The diving amplifier (fig. C–5) is the heart of the system and contains the amplifier, the tender's reproducer, the control switches, the volume controls, the tone controls, the power switch, the power jacks, the diver's jacks, and the grounding binding post. The amplifier is designed to amplify the voice from either the diver or the tender to such volume that, regardless of the surrounding noise, a message can be transmitted. In order for the system to be operated anywhere it is needed, the amplifier is designed to operate from power supplies of 12 volts dc; 110 volts dc; or 110 volts, 60 cycles ac. Details of the amplifier circuits are found in the I.C. instruction book furnished with the equipment.

Tender's Reproducer

(5) The tender's reproducer is mounted on the top of the amplifier case. This acts as a loudspeaker when the diver is talking and as a microphone when the tender is talking. Two sets of control switches are used on this model. The three spring-return switches marked "TENDER TO DIVER" provide switching for communication from the tender to any of three divers. In the normal position, the divers' reproducers act as microphones and anything any one of the divers says is heard by the tender through the diver's reproducer. When one of the switches is pressed, the tender's reproducer corresponding to the switch pressed acts as a loudspeaker while the tender talks to the diver. At this time the other two divers are disconnected from the circuit. Thus the tender can always hear messages from any of the three divers at any time that a switch is not pressed, and he can also call individually any one of the three divers.

Communication Between Divers

(6) An additional feature especially useful when several divers are working together is provided by a second set of spring-return con-

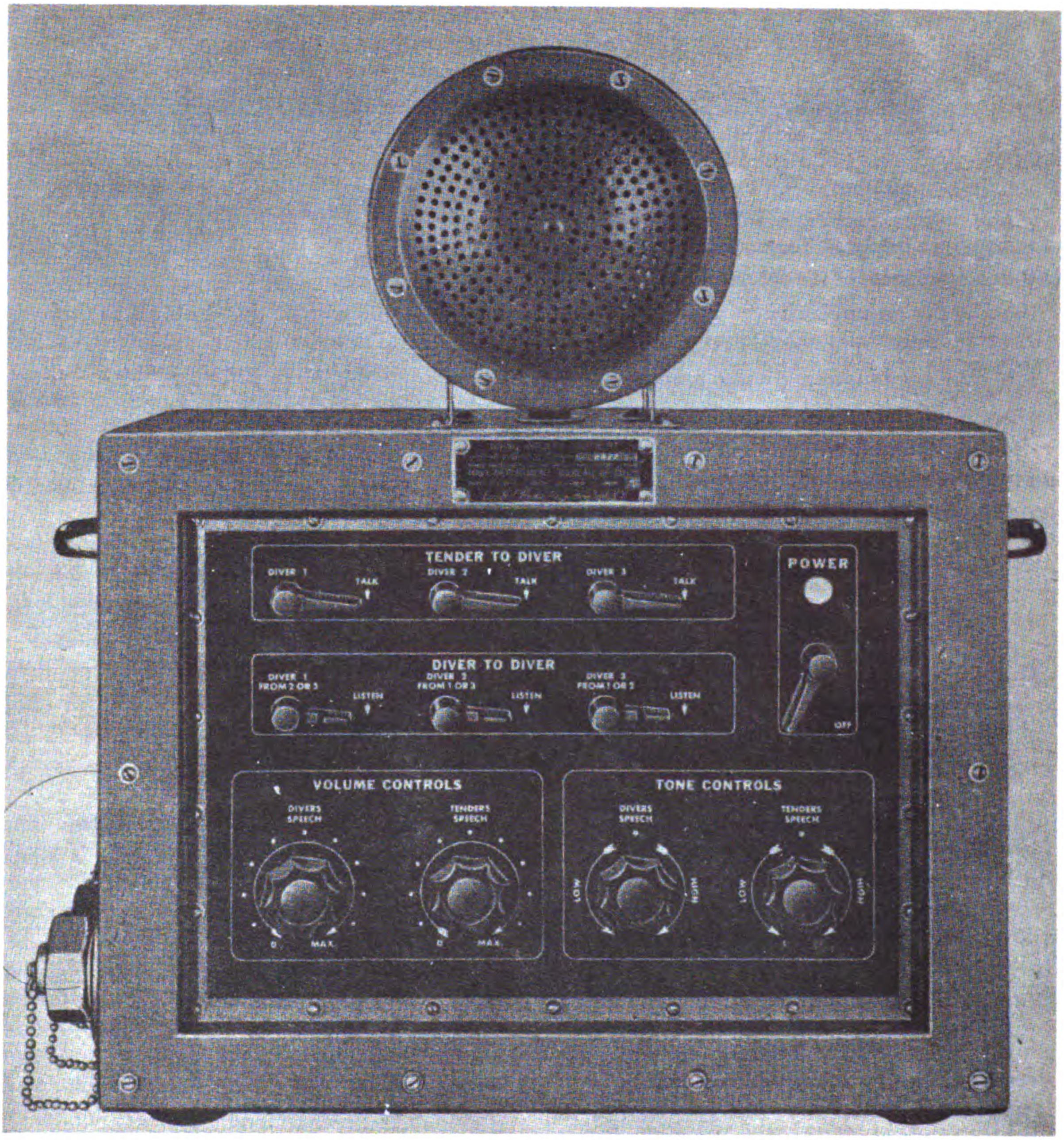

FIGURE C–5.—Diving amplifier.

trol switches marked "DIVER TO DIVER." By pressing one of these switches, the tender can make the selected diver's reproducer act as a loudspeaker while the other divers' reproducers act as microphones. Thus the diver selected can hear a message from either of the other two divers. Reversing the switching makes a return call possible. When this feature is used, the tender's reproducer is acting as a loudspeaker, thus making it possible for the tender to hear both sides of the conversation. In this manner, divers working together can actually talk with one another as they work on the assigned job.

(7) Efficient use of this feature requires a certain amount of circuit discipline. All switching

is done by the tender to relieve the diver from this responsibility. Diver No. 1 wishing to speak with diver No. 2 calls, "Diver No. 1 calling diver No. 2." The tender presses the tender-to-diver No. 1 key and says, "Go ahead," and immediately releases the tender-to-diver No. 1 key, then presses and holds the diver-to-diver key No. 2. The tender will hear No. 1's message to diver No. 2. At the end of the message, diver No. 1 will say, "Over." The tender then releases the diver-to-diver key No. 2 to talk with diver No. 1. At the end of his message, diver No. 2 also signals, "Over." Thus the call continues until it is completed, at which time diver No. 1 says, "End of call." The tender releases all switches and then tells diver No. 1, "OK."

Volume Controls

(8) Two volume controls are provided. One control adjusts the volume of sound to the diver, and the second adjusts the volume of sound to the tender. In this manner, the volume can be varied separately in each direction to provide satisfactory volume for both the diver and the tender. These controls should be adjusted before the diving is begun and as necessary during the dive. The tender should check with the diver to determine whether or not the volume at the diver's end is satisfactory.

Tone Controls

(9) Two tone controls are provided. One control adjusts the tone of the sound to the diver, and the second adjusts the tone of the sound to the tender. In the center, or zero, position, a normal tone results. The air hiss in the helmet and external noise at the tender's station may necessitate adjustment of these controls to permit maximum intelligibility. These controls are helpful in deep dives and especially when a helium-oxygen mixture is used because the voice of the diver changes. Adjustment of the tone controls aids greatly in understanding the message.

Power Switch

(10) The power switch and its associated pilot lamp are used to turn the amplifier on and off. Prior to each dive, operation of the entire intercom system should be checked at the same time that the diver checks his air valves.

Power Jacks

(11) Three power jacks are provided (see fig. C–6), one for each type of power supply—12 volts dc; 110 volts dc; and 110 volts, 60 cycles ac. Three power cords are provided, each having a different special plug to fit into one of the three jacks. After determining the type of power supply available, the power cord for that type of supply is selected, and the special plug is plugged into the appropriate jack in the amplifier. The special plug automatically makes the necessary connections for operation of the selected power source.

WARNING

Do not plug in more than one cord at a time because this will cause a direct short circuit of the power supply. It could also cause destruction of the plug and jack, and serious electrical shock.

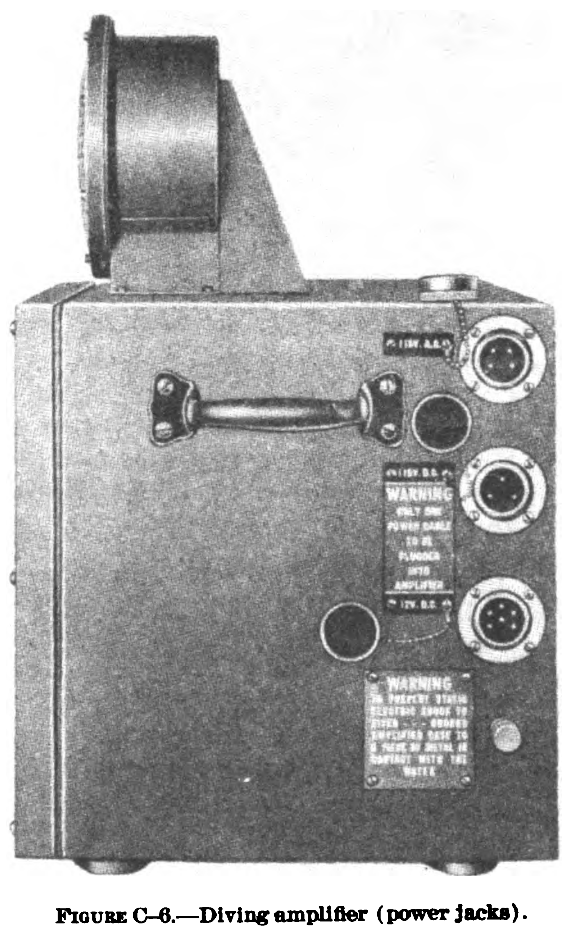

FIGURE C–6.—Diving amplifier (power jacks).

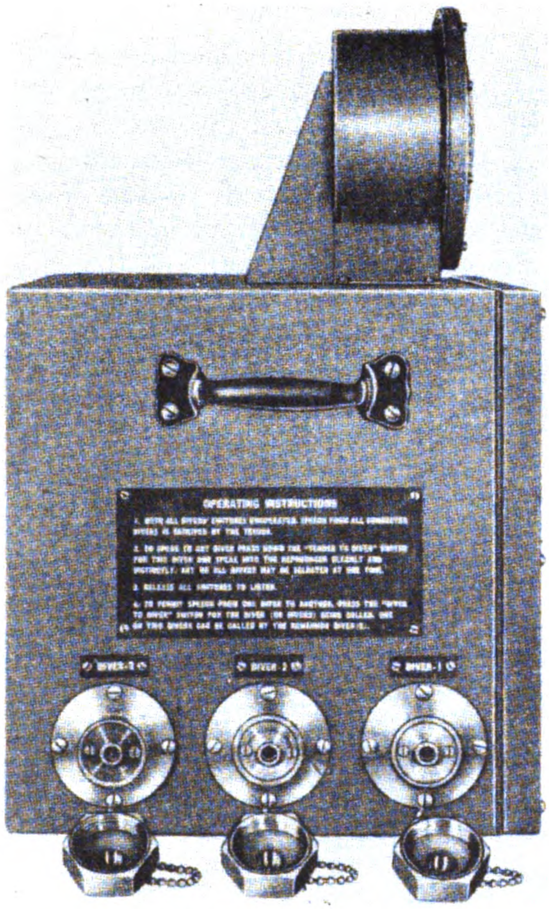

FIGURE C–7.—Diving amplifier (diver's jacks).

Diver's Jacks

(12) Three diver's jacks are provided on the side of the amplifier case (fig. C–7). Each consists of a special jack manufactured in accordance with NAVSHIPS Plan 9000–S6502–73015. Each is designed to receive a plug on the end of the diving cable and thus makes possible separate connections to the three divers.

Ground Post on Diving Amplifier

(13) When diving operations are conducted from wooden rafts, hulls, or docks, the intercom equipment is often insulated from the ground. As a result of this, a static electric charge sometimes exists between the equipment and the ground. When the helmet is placed on the diver, this charge will discharge through his body and produce electric shock. To prevent electric shock, the diving amplifier is provided with a ground binding post. A copper wire No. 10 B&S gage or larger should be run from this post to any metal that is in continuous contact with the water. The diver's metal ladder will serve as a good grounding point. If any metal-sheathed cable is used to make connection to a shore power supply, the sheath should be grounded in a similar manner.

FIGURE C–8.—Diver's reproducer.

Diver's Reproducer

(14) The diver's reproducer (fig. C–8) is a small permanent magnet with a cone-type loudspeaker especially designed to be mounted in the recess of the helmet. It is connected electrically to the diving cable through the helmet gooseneck. The helmet-jack assembly (discussed in detail under "Fittings") is mounted in the outer end of the gooseneck. A pair of wires run from the jack to the reproducer. The excess space in the gooseneck is sealed with melted beeswax to prevent water seepage. The diver's reproducer serves both as a microphone and a loudspeaker as described above.

Connecting Cables

(15) Three connecting cables (fig. C–9) are provided, each with special plugs to plug into each of the special jacks on the amplifier as described above. These plugs serve to connect the amplifier to the available power supply. Because they make the connections necessary for the particular supply, only one cable can be plugged in at once without causing a short

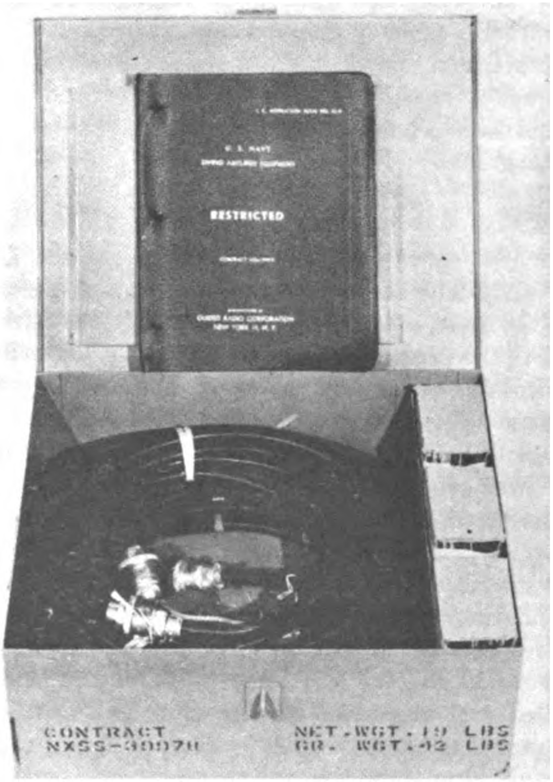

FIGURE C–9.—Connecting cable.

circuit. The other end of the 12-volt cable is provided with battery clips. The other two cables have no plugs so that the activity using the intercommunication system will attach the standard fittings that match the available receptacles.

Spare Parts Set

(16) A spare parts set (fig. C–10) including all necessary parts is provided for the maintenance and repair of the intercommunication system. To avoid possible delays in the procurement of replacement parts from supply depots, the parts in this set should be carefully kept under lock and key, and should be used only for the repair of this system.

Instruction Books

(17) The detailed information on the maintenance and repair of the diver's intercom system is available in the instruction books that accompany the systems. These books contain detailed mechanical drawings, schematic electric diagrams, and photographs of the equip-

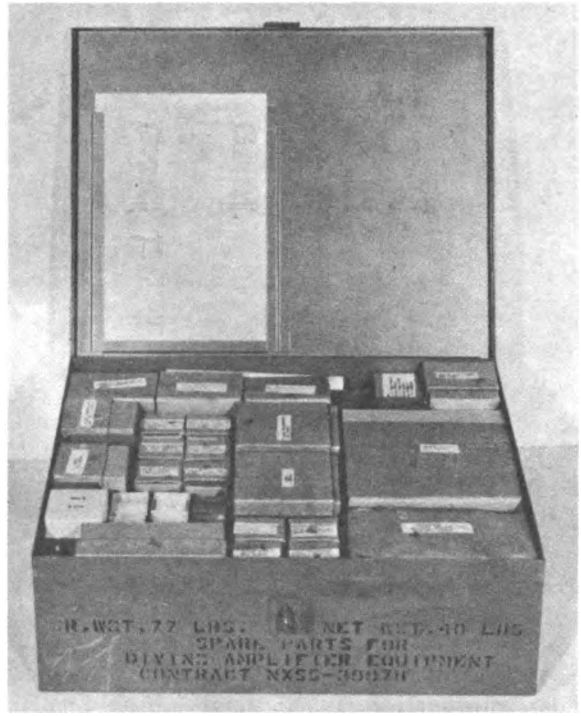

FIGURE C–10.—Spare parts set.

ment. They are the best source of information on maintenance and repair problems and should be consulted freely.

Combination Diving Amplifier and Lifeline Cable

(18) In order to carry the wire necessary for using the diving intercommunication system and to eliminate the need for a separate cable containing these wires, a special cable has been developed for use by U.S. Navy divers. This cable is called the combination diving amplifier and lifeline cable (fig. C–11). As its name implies, this cable has sufficient mechanical strength to serve as a lifeline for the diver, and at the same time to provide the electrical conductors necessary for the operation of the intercommunication system.

(19) The cable consists of a stranded steel core which is coated with high-grade rubber. Around this core four rubber-insulated wires are wound. The winding of these wires is spiral, much like a coil spring, so the cable is fairly flexible despite its size. Over these wires there is another coat of rubber and then a final coat

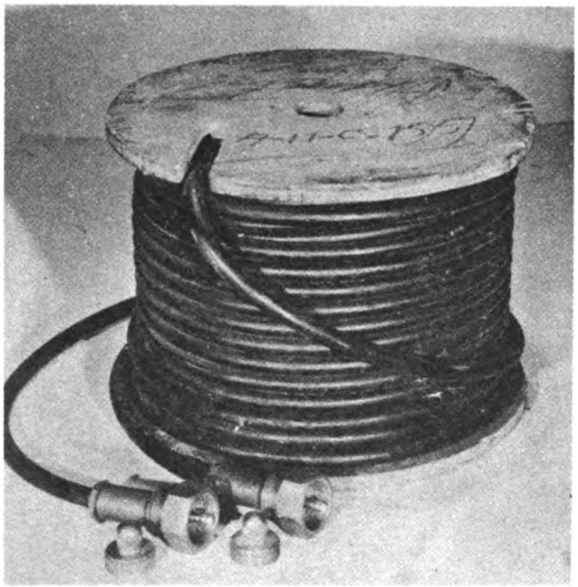

FIGURE C–11.—Amplifier and lifeline cable.

of tough, oil-resistant neoprene. The result of this construction is a tough, high-tensile-strength (2,500-pound test), water-resistant and pressure-resistant cable that is ⅝ inch in diameter and weighs about 0.35 pound per foot.

(20) The cable is usually made up in lengths of 200 or 600 feet. Each length is supplied with the following items:

- 2 male plugs (attached to cable ends).
- 1 coupling (for connecting cables together).
- 1 coupling wrench (for tightening fittings).
- 2 leather washers (used between plug and couplings).
- 1 spanner wrench (for disassembling plug).

(21) The diving cable is plugged into the diver amplifier unit of the intercommunication system. When more than one length of cable is needed, additional lengths are added by connecting the two male plugs with a female coupling. The plugs and couplings are constructed heavily enough so that both a strong mechanical connection as well as a good electrical connection is made. The cable is secured at the diver's end by lashing it to the breastplate. It then passes to the helmet gooseneck where the plug is attached, thus making positive mechanical and electrical connections to the helmet. A leather washer is inserted into each connection to act as a spacer and watertight gasket. The plug on the end of the diving amplifier and lifeline cable is made up to withstand a 1,000-pound static load.

Care To Be Used in Handling Amplifier Equipment

(22) The diving intercommunication system is designed to be as rugged as possible consistent with the permissible weight. However, it fundamentally remains a piece of electrical equipment. For this reason, the diving amplifier should be carefully handled to avoid dropping. Power cables should be attached only one at a time in order to avoid a short circuit.

(23) Every effort should be made to keep water, especially salt water, out of the amplifier and the cable fittings. The helmet reproducer is especially vulnerable to mechanical and water damage, and the helmet should always be handled with consideration for this vital unit. To avoid damage, the male section of the diving cable plug should be suitably protected with a screw cap as shown on NAVSHIPS Plan 9000–S6502–73009. This is especially important on the plugs with a plastic base on the plug insert assembly.

(24) The internal parts of the amplifier should be kept dry at all times. If water accidentally gets into the amplifier, the units should be carefully dried out before the power is connected.

Failure of Amplifier

(25) If the amplifier becomes inoperative, the power supply should be checked to see if it is energized, and, in the case of dc, the power supply should be checked for the right polarity. If a storage battery is used as a source of power, the battery voltage should be at least 11.5 volts with the amplifier turned on. If the power circuit is unsatisfactory, the fuse posts on the amplifier should be removed with a screwdriver, and the fuses should be examined for burnouts. Defective fuses should be replaced with good ones of the rating shown in the instruction book.

(26) If the foregoing procedure does not restore proper operation, the most likely source of trouble is failure of one or more of the vacuum

tubes or failure of the power-supply vibrator. To check or replace these tubes, the amplifier must be removed from its case by removing the panel screws. This will enable the main amplifier panel, the cover, and the rear panel to be withdrawn from the case as a unit. Before removing the tubes, the locking clamps around the tube bases must be loosened. Defective tubes and vibrators should be replaced with new ones. Only tubes of the type furnished with the amplifier should be used. The tubes are not interchangeable, and replacement tubes should be installed in the sockets marked for the particular type of tube used.

(27) If the foregoing check does not disclose the cause of failure, the trouble may be caused by an open or short circuit in the amplifier connections or by failure of component parts. The circuit may be checked by reference to the respective wiring diagrams and list of parts as shown in the instruction book accompanying the equipment.

Handling of Combination Diving Amplifier and Lifeline Cable

(28) The combination diving amplifier and lifeline cable should be carefully unreeled when received on board. The coil of cable should be placed on a revolving platform or reel as it is received, and uncoiled as the platform or reel revolves. The cable should not be uncoiled like a rope because this will twist and kink the cable. Kinks especially should be avoided because they may damage the rubber cover or displace the conductor wires, thus causing early failure of the cable.

(29) It is unnecessary to test the cable for strength because the central core, which is the strength member, is made of corrosion-resistant steel, has an ample factor of safety, and is not susceptible to deterioration. Unfortunately, however, this is not the case with the conductor wires made of copper which may in time stretch or break, thus impairing or destroying the electrical circuit. When the breakage occurs, it is usually at the points of greater flexing of the cable. The points of greatest flexing are usually a few inches from either end of the cable due to the bend in the cable at these points when it is under tension. Care should be taken to prevent the cable from getting a sharp nip or permanent bend at these points. Experience will facilitate the locating of such breaks, and a study of the drawings showing the construction of jackplugs will enable the jackplugs to be assembled and reassembled when removing defective sections of the cable.

(30) Continuity of circuit or grounds may be determined by test with a megger, a test lamp, or an ohmmeter, following the same procedure for determining an open or a ground in any other circuit. In testing the cables, remember that there is a complete electrical circuit from one plug to the other through the cable core. If through any cause an open or a short circuit develops in the cable and causes failure of the communication circuits, the jackplug at the damaged end of the cable should be removed, the faulty section of the cable cut off, and the jackplug replaced.

(31) Removal of the jackplug (fig. C–12) involves the following operations:

(*a*) Unscrewing the gland nut at rear of the plug housing.

(*b*) Removing packing.

(*c*) Removing locknut at front of plug housing with supplied spanner wrench.

(*d*) Heating plug housing to soften the sealing compound.

(*e*) Sliding plug housing back on cable away from plug.

(*f*) Loosening connections to plug terminals and remove plug.

(*g*) Melting solder which secures stainless-steel core in the anchor plug and removing the wood-screw wedge and anchor plug.

The cable may now be cut back until it is evident from the appearance of the butt end that all the damaged cable has been removed, and cut back until the communication lines test through.

(32) To reassemble the jackplug, the procedure is as follows:

(*a*) Slide gland nut and jackplug housing onto cable.

(*b*) Remove the two outer rubber coverings for a distance of about 4 inches, untwisting the four conductors and removing the rubber covering of the stainless-steel core also for about 4 inches.

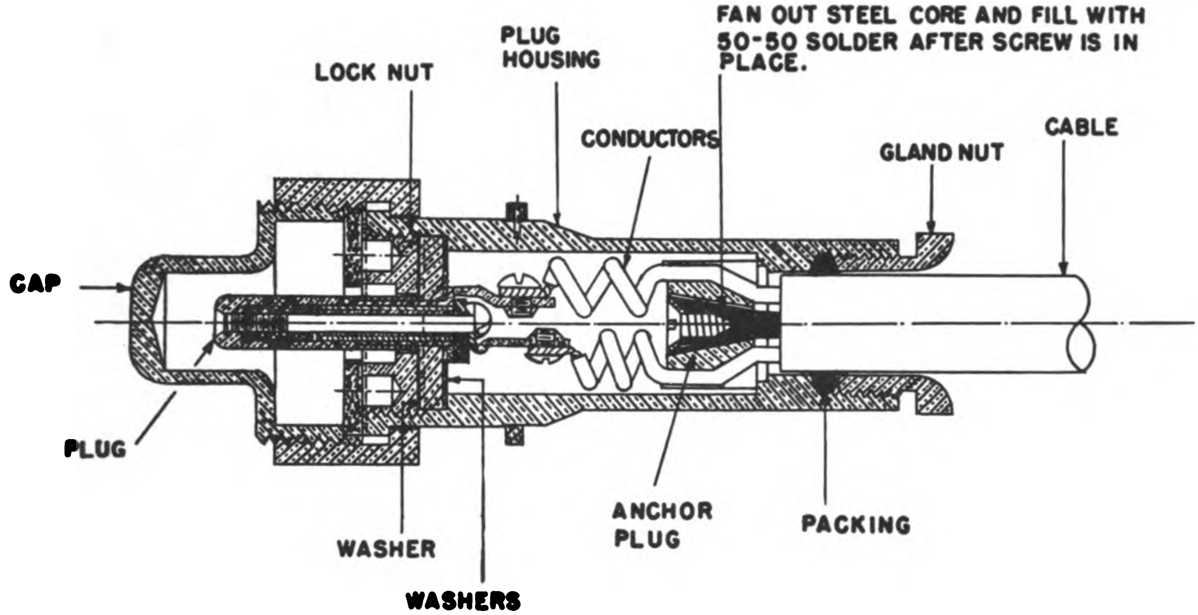

FIGURE C-12.—Jackplug.

(*c*) Separate the exposed strands of steel core and tin thoroughly.

(*d*) Slip anchor plug over the tinned strands and bring up as close as possible to rubber covering.

(*e*) Distribute strands around circumference of hole in plug and drive in wood-screw wedge.

(*f*) Solder the steel core and wedge securely into anchor plug.

(*g*) Cut off loose ends of steel core even with anchor plug and smooth with file.

(*h*) Bare the ends of the conductors and twist together into two pairs—red with green, black with white. It is very important that this color coding be observed.

(*i*) Form an eye in the end of each pair and solder.

(*j*) Pull plug housing down over anchor plug as far as possible. Length of conductors should be such that the eyes project about ¼ inch out of plug housing.

(*k*) Several turns of suitable packing material should be inserted in the gland, and the gland nut screwed in and pulled up tight.

(*l*) Place the thin leather washer over conductors and attach conductors to plug terminals making sure that the red-green pair is connected to the side terminal, and the black-white pair to the center terminal.

(*m*) Pour melted sealing compound of beeswax into the open end of the housing to within ¼ inch of the plug seat.

(*n*) While the sealing compound is still soft, seat the jackplug in plug housing, making certain that the thin leather washer is properly situated on seat. Care must be taken to see that all space in the plug housing is filled with the sealing compound.

(*o*) Screw in locking nut and pull up tight to complete the assembly.

(33) In case a bubble forms in the outer rubber covering of the cable due to leakage of compressed air from the diver's helmet, it is not necessary to cut off the injured section of the cable unless the communication circuit is opened. The correct procedure is to puncture the bubble and wrap the puncture with several layers of rubber tape, with plenty of rubber cement being used between layers. The rubber tape should be covered with one layer of friction tape and the whole patch then thoroughly shellacked. Before the cable is returned to service after a repair, it is essential that the cable jackplug be opened and inspected for leaks in the sealing compound. If any are found, the plug should be resealed. A similar inspection should be made of the telephone gooseneck fitting on the helmet, and necessary repairs made.

Care of Reproducers

(34) The reproducer units of the standard diving system are exceptionally rugged and unsusceptible to the trouble usually experienced from the effect of moisture. Ordinarily, no serious damage is caused by short submersion, but continued submersion or continuous exposure to moisture will result in corrosion of the metal parts and the grounding or short circuiting of the coils. If any of the units should be accidentally submerged in salt water, they should be washed out with fresh water and dried out by exposure to heat. Care should be taken, however, that the applied heat is not sufficient to burn the insulation of the wire. If any of the units become inoperative due to the collection of dirt, they should be carefully dismantled and cleaned. The diaphragms and pole pieces especially should be kept free from dirt and sediment. After use, the units should be wiped dry with a clean rag to remove all moisture before storing.

Electrical Connections

(35) The electrical connections between the diver's reproducer and the amplifier, and between cable lengths are made through the jackboxes. The new-style jackbox is shown in figure C–13 and the old style in figure C–14. The corresponding helmet goosenecks are shown in figures C–15(*a*) and C–15(*b*).

(36) To install the helmet gooseneck jack into the gooseneck—

(*a*) Solder a 12-inch insulated wire to each of the terminals of the jack if leads are not furnished on the jack unit.

(*b*) Insert the jack element, wires down, into the gooseneck and secure with two screws.

(*c*) Trim and attach leads to the reproducer unit and secure the reproducer unit in place.

(*d*) Pour melted beeswax into the helmet gooseneck from inside the helmet to produce a watertight seal.

Signal Halyard

(37) A 1-inch braided-cotton signal halyard is used for securing the hose, amplifier, and lifeline cable to the eyelets on the helmet breastplate.

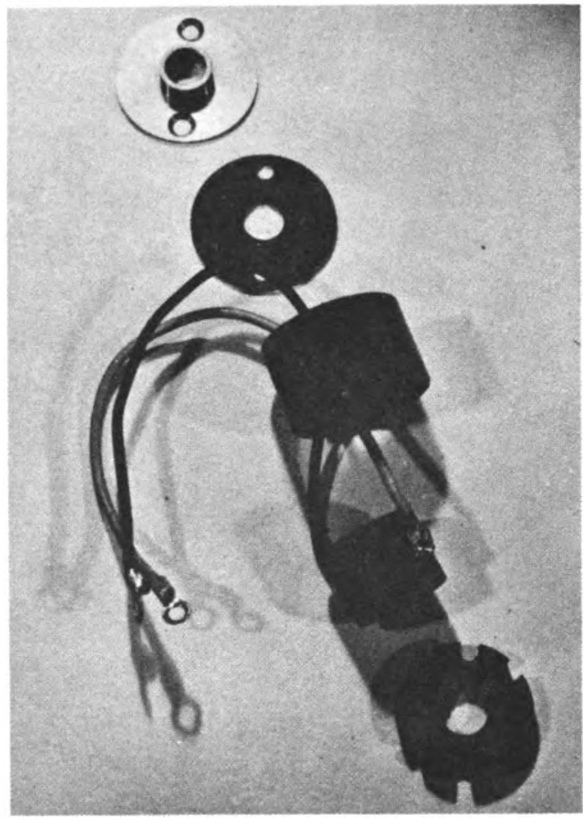

FIGURE C–13.—Jackbox (new style).

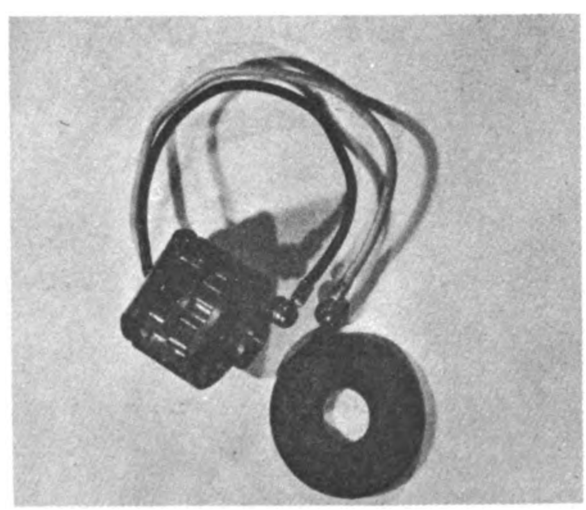

FIGURE C–14.—Jackbox (old style).

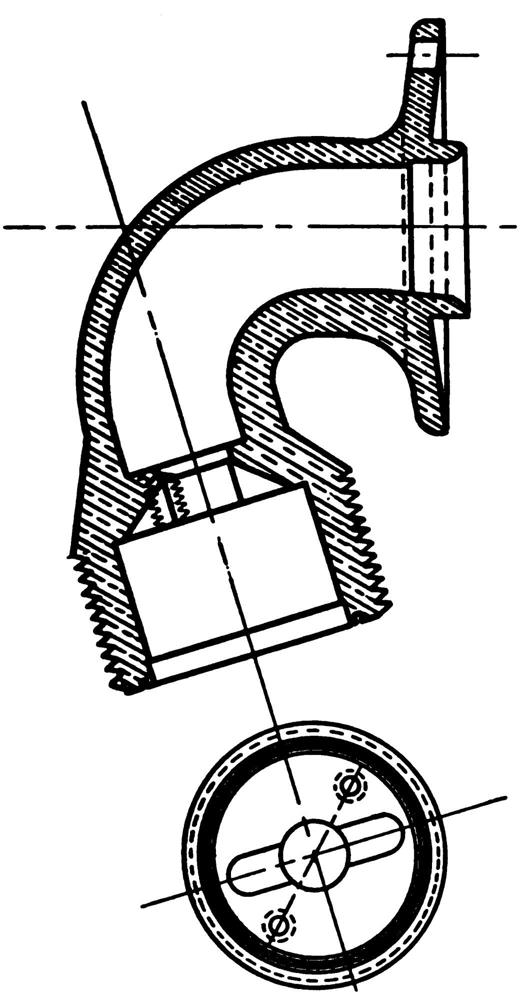

FIGURE C–15(*a*).—Helmet gooseneck requiring use of new-style jackbox.

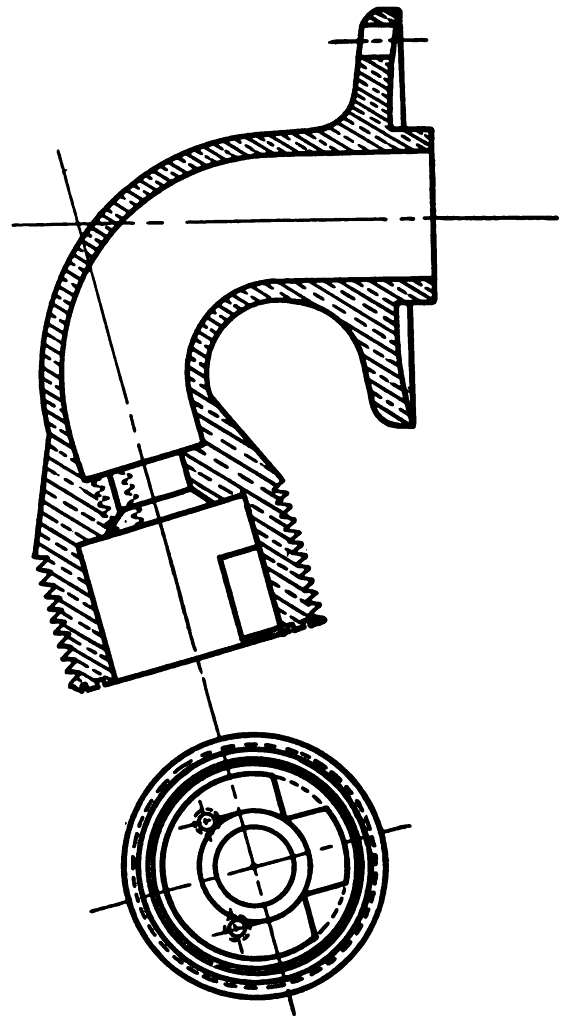

FIGURE C–15(*b*).—Helmet gooseneck requiring use of old-style jackbox.

U.S. NAVY DIVING MANUAL

APPENDIX D

SELF-CONTAINED UNDERWATER BREATHING APPARATUS TECHNICAL MANUALS AND INFORMATION

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D–A. WRIST DEPTH GAGE, MK I MOD 0

General

The Mk I Mod 0 wrist depth gage (see fig. D–1), Federal Stock No. HF 4220–639–8999, is a precision gage for the use of scuba swimmers or divers to show the depth of dives in sea water, to a maximum depth of 200 feet. The instrument is manufactured for the U.S. Navy by the Bendix Aviation Corp., Friez Instrument Division, as part No. 1130284–1.

Description

The wrist depth gage essentially consists of a pressure-sensing diaphragm, a gear movement, and an indicating dial enclosed in a hermetically sealed, cylindrical metal and glass case (see fig. D–2). The gage is equipped with a removable dial cover and an adjustable wrist strap (see fig. D–1).

The wrist depth gage without the dial-cover strap and dial cover attached is 2 inches in diameter and $1\frac{5}{32}$ inches in height. It weighs 5.8 ounces in air and 3.7 ounces in sea water. With the dial-cover strap and dial cover attached, the gage is $2\frac{1}{4}$ inches in diameter and $1\frac{5}{8}$ inches in height. It weighs 7.0 ounces in air and 4.4 ounces in sea water.

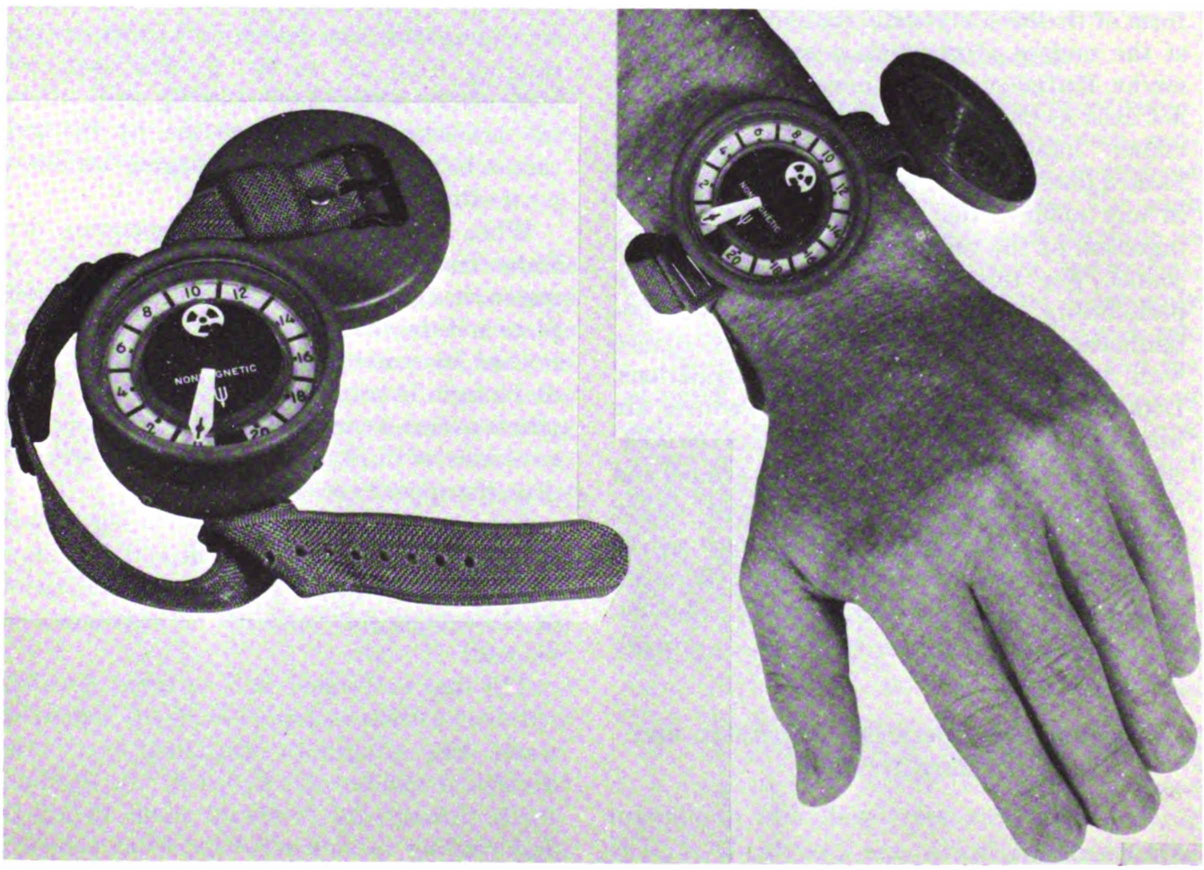


FIGURE D–1.—Wrist depth gage, Mk I Mod 0.

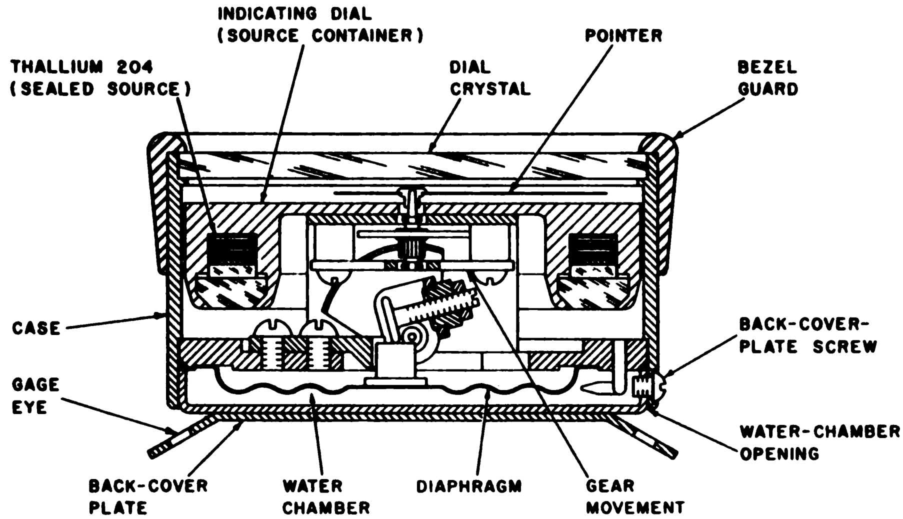


FIGURE D–2.—Sectional view.

Radioactivity

The indicating dial is a sealed source containing approximately 1.6 millicuries of radioisotope thallium-204, a pure beta emitter, in the form of thallus molybdate. Radiation intensity, at the surface of the dial, is approximately 1 mr/hr. Radiological contamination hazard does not exist as long as the dial (sealed source) remains intact. Radiological contamination hazard does exist if the dial has been damaged in any manner that permits contact with or ingestion of the radioactive compound by personnel. For this reason, the gages must be periodically inspected for radiological contamination, and used and handled in accordance with Atomic Energy Commission regulations. Detailed instructions for these procedures are issued by NAVSHIPS. The dial bears the AEC conventional radiation symbol. This symbol and other pertinent radioisotope data appear on the back of the gage. These markings must not be obliterated or removed from the gage. Gages are free from radiological contamination when delivered by the manufacturer to the supplying activity.

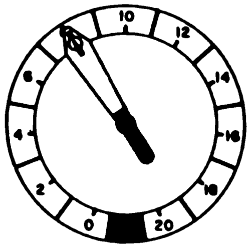
Construction, Operating Principles, and Characteristics

The dial, gear movement, and diaphragm are assembled in the case (see fig. D–2). The case is then partially evacuated through a small tube and then hermetically sealed. A removable back-cover plate, installed with screws, forms a water chamber, protects the diaphragm, and provides means of attaching the wrist strap and dial-cover strap. This type of construction insures accurate gage operation in temperatures ranging from 32° to 90° F. The back-cover plate can be removed for cleaning purposes, but the hermetically sealed section of the gage cannot be opened without damaging the instrument after initial sealing.

When submerged, as in a descending dive, water enters the water chamber through the water-chamber opening between the back-cover plate and the case, and the diaphragm is forced inward by water pressure. The motion of the diaphragm is transferred to the pointer by the gear movement causing the pointer to operate in a clockwise direction. During an ascending dive, the opposite occurs.

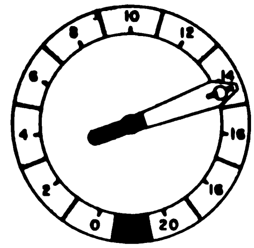
Because there is no appreciable lag between the motion of the diaphragm and the movement of the pointer, instantaneous indications of the submerged depth of the instrument can be read.

The dial is divided into 20 equal divisions, with each division representing 10 feet of sea water. Beginning with zero index, every other division is numbered; i.e., 0, 2, 4, 6, 8, 10, and so forth, through 20. To obtain actual depth, the dial reading is multiplied by 10 as shown in figure D–3.



EXAMPLE A

Indication = 8
8 x 10 = 80 ft. depth



EXAMPLE B

Indication = 14.4
14.4 x 10 = 144 ft. depth

FIGURE D-8.—Use of wrist depth gage.

The gage is accurate to within plus or minus 1 foot of the true depth in the 0- to 50-foot range and to within plus or minus 3 feet in the 50- to 200-foot range. Gage accuracy is not materially affected by temperatures ranging between 32° and 90° F. The gage may be submerged to a depth of 300 feet without damage.

The gage is nonmagnetic, indicating that the magnetic effect of the instrument is 0.10 milligauss or less. This fact is signified by the symbol on the dial.

The gage is corrosion resistant and can withstand shock, vibration, and underwater blast close to the limits of human endurance.

Use

The gage may be used with or without the dial-cover strap threaded through the gage eyes. When the dial cover is strapped over the dial, the cover protects the dial crystal and prevents detection of the illuminant dial of the gage when being used by personnel operating close to the surface at night. The dial cover should cover the dial crystal whenever the gage is not in use.

To use the gage with the dial-cover strap attached, fasten the gage to the wrist with the wrist strap. To read the indicating dial, unbuckle the dial-cover strap and lift the cover from the gage. When the dial-cover strap is threaded through the gage eyeholes, the dial cover will not separate from the gage.

When desired, the dial-cover strap and dial cover are removed from the gage as follows:

(*a*) Remove the wrist strap by pulling it through the gage eyes.

(*b*) Pull the dial-cover strap, with dial cover attached, through the gage eyes.

(*c*) Rethread the wrist strap through the gage eyes.

The dial cover and dial-cover strap should be carried on the equipment belt when the cover is not attached to the gage. The gage, with or without the dial cover, can also be carried on the equipment belt when desired.

Care and Maintenance

Although the gage is constructed of corrosion-resistant materials and is shock resistant, serious and irreparable damage to the instrument can be caused by neglect and abuse. The gage should receive the same care and attention as any other high-grade, precision instrument, such as a fine watch. Flush and thoroughly clean the gage with fresh water after each use.

The opening to the water chamber and the chamber itself should be kept free of debris and sediment by periodically removing the back cover and flushing the pressure chamber and back-cover plate with fresh water. When the back-cover plate is removed from the instrument, extreme care must be exercised to prevent damage to the diaphragm by denting or puncturing. Do not tamper with the small exhaust tube, because this may cause rupture of the hermetic seal. Never use the gage unless the back-cover plate is in place.

Do not attempt to open the gage by removing the diaphragm or crystal. The edges of these parts are hermetically sealed to the case and once the hermetic seal is broken, it cannot be resealed. Furthermore, opening of a gage may cause exposure to radiological contamination. Back-cover-plate screws, a wrist strap, a bezel guard, and a dial-cover strap and dial cover comprise the repair kit, Federal Stock No. HR 4220–651–5731.

The joint between the dial crystal and the case is particularly subject to damage when the gage is hit or dropped against other objects. A rubber bezel guard protects this joint and should remain on the gage at all times. Rupture of the hermetic seal can be detected by an indication of approximately 15 on the dial when the gage is out of the water.

Periodically check the calibration of the gage by placing it in a recompression chamber or by comparing indications in sea water with the depths shown by a sounding line.

Summary

Keep dial-cover strap on gage and dial cover over dial when gage is not in use. Keep dial-cover strap on equipment belt when dial cover is not attached to gage. Flush gage with fresh water after each use. Keep bezel guard and back-cover plate in place. Periodically remove debris and sediment from water chamber. Dispose of radioactively contaminated gages in accordance with Atomic Energy Commission regulations. Periodically check calibration. Your gage is as reliable as you keep it!

D–B. WRIST DEPTH GAGE, MK II MOD 0

1.1 GENERAL

1.2 Mk II Mod 0 wrist depth gage is a precision gage for the use of scuba swimmers or divers indicating the depth of dives in sea water to a maximum depth of 50 feet (see fig. D–4). The instrument is manufactured by the Bendix Aviation Corp., Friez Instrument Division, as part No. 11499288.

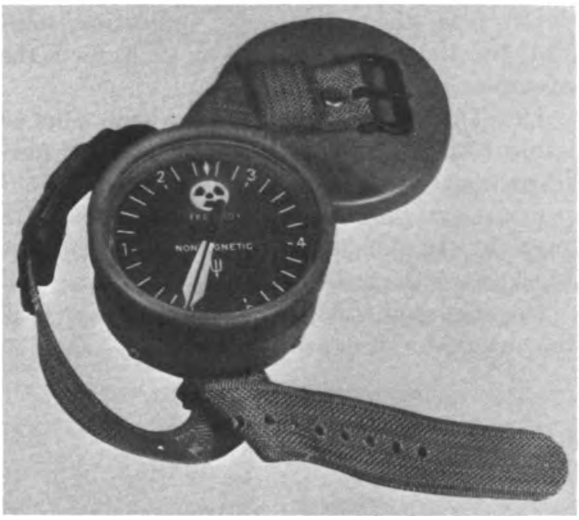


FIGURE D–4.—Wrist depth gage, Mk II Mod 0.

2.1 DESCRIPTION

2.2 The wrist depth gage essentially consists of a pressure-sensing diaphragm, a gear assembly and an indicating dial enclosed in a hermetically sealed, cylindrical metal and glass case. The gage is equipped with a removable dial cover and an adjustable wrist strap.

2.3 The wrist depth gage without the dial-cover strap and dial cover attached is 2 inches in diameter and $1\frac{5}{32}$ inches in height. It weighs 5.8 ounces in air and 3.7 ounces in sea water. With the dial-cover strap and dial cover attached, the gage is $2\frac{1}{4}$ inches in diameter and $1\frac{5}{8}$ inches in height. It weighs 7.0 ounces in air and 4.4 ounces in sea water.

3.1 RADIOACTIVE INDICATOR DIAL

3.2 The indicating dial (see fig. D–5) contains approximately 7 millicuries of radioisotope PM 147, and moderate beta energy in the form of microspheres. Radiation intensity at the surface of the dial is approximately 1 mr/hr. The indicating dial is sealed in the gage case. Radiological contamination hazard does not exist as long as the dial remains intact.

WARNING

Radiological contamination will exist if the dial is damaged in any manner that permits contact with or ingestion of the radioactive compound by personnel.

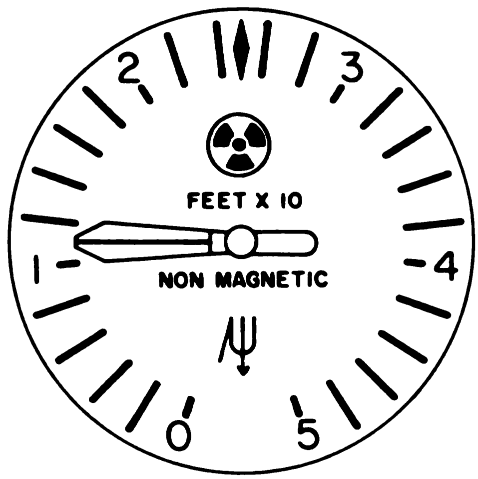


FIGURE D–5.—Wrist depth gage dial.

3.3 The gages must be periodically inspected for radiological contamination, used and handled in accordance with Atomic Energy Commission regulations. Detailed instructions for these procedures are issued by NAVSHIPS. The dial bears the conventional AEC radiation symbol. This symbol and other pertinent radioisotope data appear on the back of the gage.

NOTE

The markings must not be obliterated or removed from the gage. Gages are free from the radiological contamination when delivered by the manufacturer to the supplying activity.

4.1 OPERATING PRINCIPLES AND CHARACTERISTICS

4.2 Figure D–6 shows the piece part arrangement within the equipment. The upper section of the case contains the dial and the gear assembly. It is partially evacuated of air and then hermetically sealed. This action is taken to provide temperature compensation, resulting in accurate gage operation from temperatures ranging between 32° and 90° F. The lower section of the case (water chamber) is formed when the removable back-cover plate, which is held in place by a snapring, is placed into the inner circumference of the bottom of the gage. The back-cover plate can be easily removed to allow cleaning of the water chamber.

CAUTION

Do not open the hermetically sealed section of the equipment.

4.3 When submerged, as in a descending dive, water enters the water chamber through the space between the back-cover plate and the side of the case. The water in the chamber acts upon the diaphragm causing a compression of the diaphragm relative to the water pressure. The motion of the diaphragm is transferred to the dial pointer through the gear movement, causing the pointer to operate in a clockwise direction.

4.4 Because there is no appreciable lag between the motion of the diaphragm and the movement of the pointer, instantaneous indications of the depth of the instrument can be read. A second diaphragm has been provided to protect the movement against overpressure.

4.5 The dial is divided into 25 equal divisions. The first division mark is designated by the number zero, and each fifth division thereafter is assigned a number. To calculate actual depth from the dial pointer indication, multiply the dial pointer reading by 10. Refer to the examples shown in figure D–7.

4.6 The gage is accurate to within plus or minus 1 foot of the true depth from 0 to 50 feet. Gage accuracy is not materially affected by temperatures ranging between 32° and 90° F. The gage may be submerged to a depth of 150 feet (66.6 psi) without damage.

4.7 The gage is nonmagnetic, indicating that the magnetic effect of the instrument is 0.10

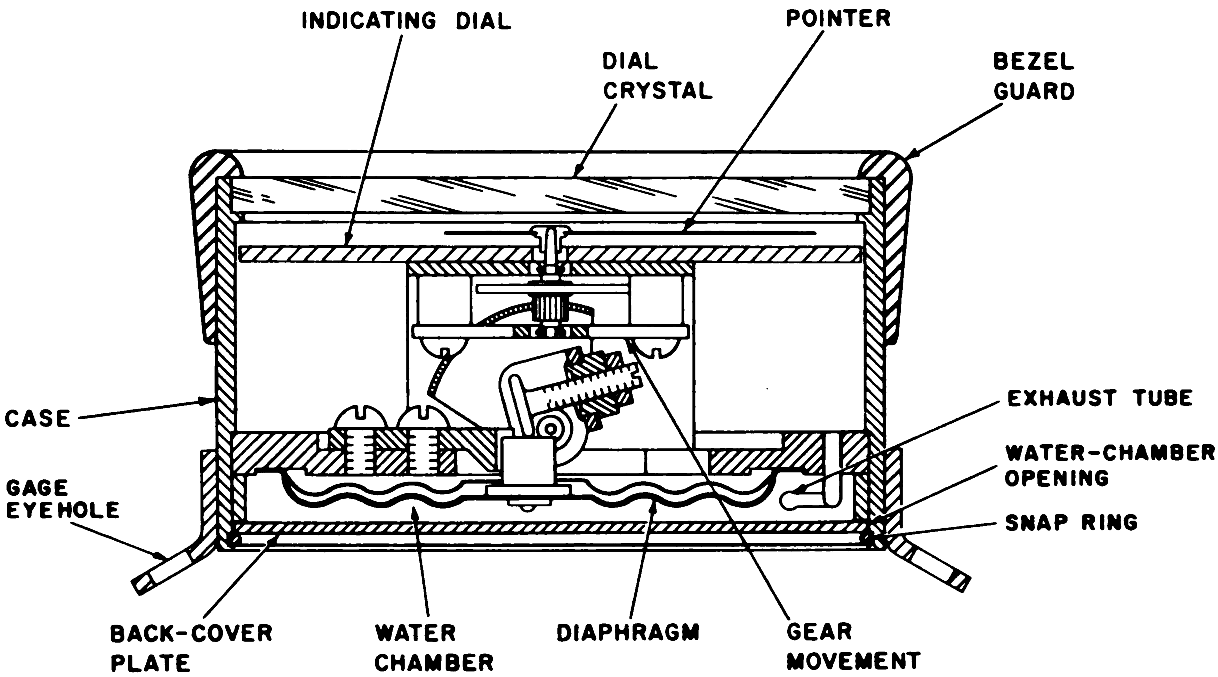
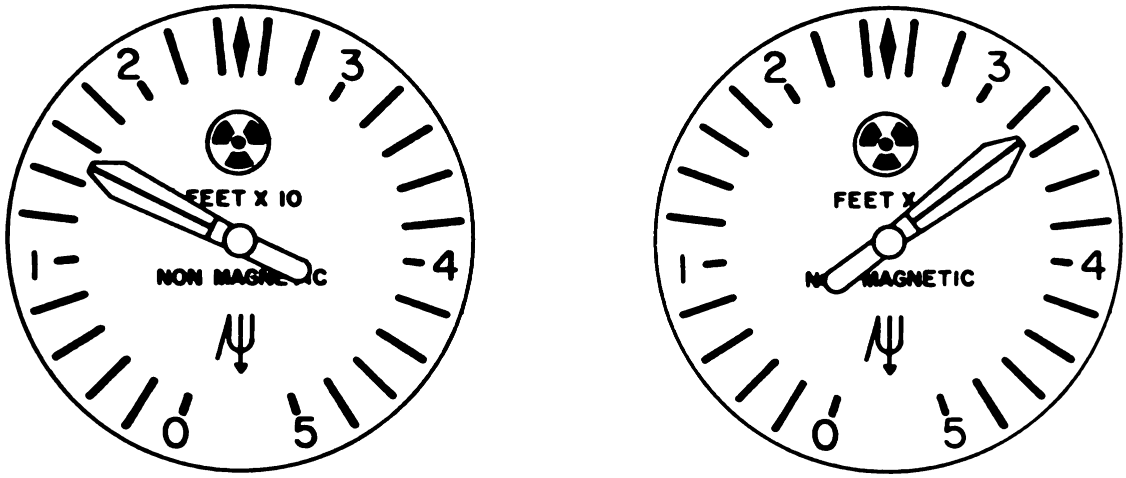


Figure D–6.—Wrist depth gage, sectional view.



Example A:
Indication = 1.5
1.5 x 10 = 15 ft. depth

Example B:
Indication = 3.3
3.3 x 10 = 33 ft. depth

FIGURE D–7.—Dial indicator conversion.

milligauss or less. The nonmagnetic condition is signified by the symbol on the dial.

4.8 The gage is corrosion resistant and can withstand shock, vibration, and underwater blast close to the limits of human endurance.

5.1 USE OF GAGE

5.2 The gage may be used with or without the dial cover. The dial cover is attached to the gage by the dial-cover strap that is inserted through the eyeholes of the gage. The dial cover protects the dial crystal and prevents detection of the illuminant dial of the gage when being used by personnel operating close to the surface of the water at night.

5.3 To use the gage with the dial-cover strap attached, fasten the gage to the wrist with the wrist strap. To read the indicating dial, unbuckle the dial-cover strap and lift the cover from the gage. When the dial-cover strap is threaded through the gage eyeholes, the dial cover will not separate from the gage.

5.4 When desired, the dial-cover strap and dial cover are removed from the gage as follows:

(*a*) Remove the wrist strap by pulling it through the gage eyeholes.

(*b*) Pull the dial-cover strap, with dial cover attached, through the gage eyeholes.

(*c*) Rethread the wrist strap through the gage eyeholes.

5.5 The dial cover and dial-cover strap should be carried on the equipment belt when the cover is not attached to the gage. The gage, with or without the dial cover, can also be carried on the equipment belt when desired.

6.1 MAINTENANCE

6.2 Although the gage is constructed of corrosion-resistant materials and is shock resistant, serious and irreparable damage to the instrument can be caused by neglect and abuse. The gage should receive the same care and attention as any other high-grade instrument. Clean the water chamber by rinsing with fresh water after each use if the gage has been submerged in salt water. To obtain access to the water chamber, remove the snapring which will allow the back plate to drop out (see fig. D–6).

CAUTION

Be sure that the opening to the water chamber is kept free of sediment.

When the back-cover plate is removed from the instrument, extreme care must be exercised to prevent damage to the diaphragm. Do not tamper with the small exhaust tube, because this may cause a rupture of the hermetic seal.

CAUTION

Never use the gage unless the back-cover plate is in place and secured.

6.3 Do not attempt to open the gage by removing the diaphragm or crystal. The edges of these parts are hermetically sealed to the case and once the hermetic seal is broken it cannot be resealed.

WARNING

Opening the gage may cause exposure to radiological contamination.

6.4 The joint between the dial crystal and the case is particularly subject to damage when the gage is hit or dropped against other objects. A rubber bezel guard protects this joint and should remain on the gage at all times. A subzero reading is an indication of a rupture of the sealed case.

6.5 CALIBRATION CHECK

Periodically check the calibration of the gage by placing it in a compression chamber or by comparing indications in sea water with the depths shown by a sounding line.

7.1 MAINTENANCE SUMMARY

7.2 The following comments represent a summary of maintenance practices that will improve the use and longevity of the gage.

(*a*) Keep dial-cover strap on gage and dial cover over dial when gage is not in use.

(*b*) Keep dial-cover strap on equipment belt when dial cover is not attached to gage.

(*c*) Flush gage with fresh water after each use.

(*d*) Keep bezel guard and back-cover plate in place.

(*e*) Keep opening to maintain water chamber free of sediment and corrosion.

(*f*) Periodically check gage calibration.

(*g*) Dispose of radioactive material in accordance with Atomic Energy Commission regulations.

(*h*) To order the wrist strap or cover strap and cover, use the following:

(*1*) Wrist strap—Bendix Friez part No. 1132525.

(*2*) Cover strap and cover—Bendix Friez part No. 1132526–1.

D–C. AQUA-LUNG UNDERWATER BREATHING APPARATUS

SECTION 1 GENERAL INFORMATION

1.1 GENERAL

1.2 This instruction manual comprises installation, operation, maintenance, and repair information, with an illustrated parts breakdown, for Aqua-Lung underwater breathing apparatus, part No. 0659–00, manufactured by U.S. Diver Co., Santa Ana, Calif.

1.3 FUNCTION AND PURPOSE OF EQUIPMENT

1.4 The Aqua-Lung (fig. D–8) is a self-contained, regulated, compressed-air breathing mechanism, for use on underwater missions. Prolonged immersion is made possible by the compressed-air supply stored in two high-pressure, preaged, aluminum air cylinders. The air cylinders are rechargeable from any convenient air-pressure source that is properly filtered and dehumidified for underwater breathing use. The air supply to the diver from the air cylinder is controlled by an automatic two-stage demand-type regulator, and delivered to the diver through a neoprene air hose and mouthpiece. Low-magnetic-effects materials, meeting the requirements of Military Specification MIL–M–19595, are used in the Aqua-Lung.

WARNING

Replacement parts for equipment covered in this manual shall be requisitioned only from Ships Parts Control Center, Mechanicsburg, Pa. Requests shall specify parts to be antimagnetic.

SECTION 2 DESCRIPTION

2.1 GENERAL

2.2 The Aqua-Lung is comprised of two basic units: the demand-regulator assembly (fig. D–9) and the air-cylinder assembly (see fig. D–10). The air cylinders are secured together by two aluminum bands. The harness assembly, which provides a means for securing the Aqua-Lung to the diver, is attached to the two aluminum bands on the air cylinders. A cylinder-block manifold assembly connects the air supplies of the two air cylinders. The demand-regular assembly is attached to a T in the center of the manifold assembly.

2.3 *Demand-Regulator Assembly.*—The demand-regulator assembly is a two-stage mechanism that reduces the air pressure in the cylinder-block manifold assembly to a breathable pressure at the mouthpiece of the Aqua-Lung. The first regulation stage reduces the 3,000 psi from the air cylinders to approximately 110 psi. The second regulation stage reduces the 110-psi pressure to a pressure at the Aqua-Lung mouthpiece equal to the pressure of the surrounding environment.

(*a*) *First-stage regulation.*—When there is no pressure in the demand regulator, the high-pressure (HP) seat in the regulator is held open by the force of the high-pressure diaphragm spring which is located beneath the high-pressure diaphragm. The high-pressure diaphragm is linked mechanically to the high-pressure seat through a pin support and a pin. A return spring, also mechanically linked to the high-pressure seat, opposes action of the high-pressure diaphragm spring; the diaphragm spring, however, exerts a greater force than does the return spring, and the high-pressure seat normally stays open. When a high-pressure air

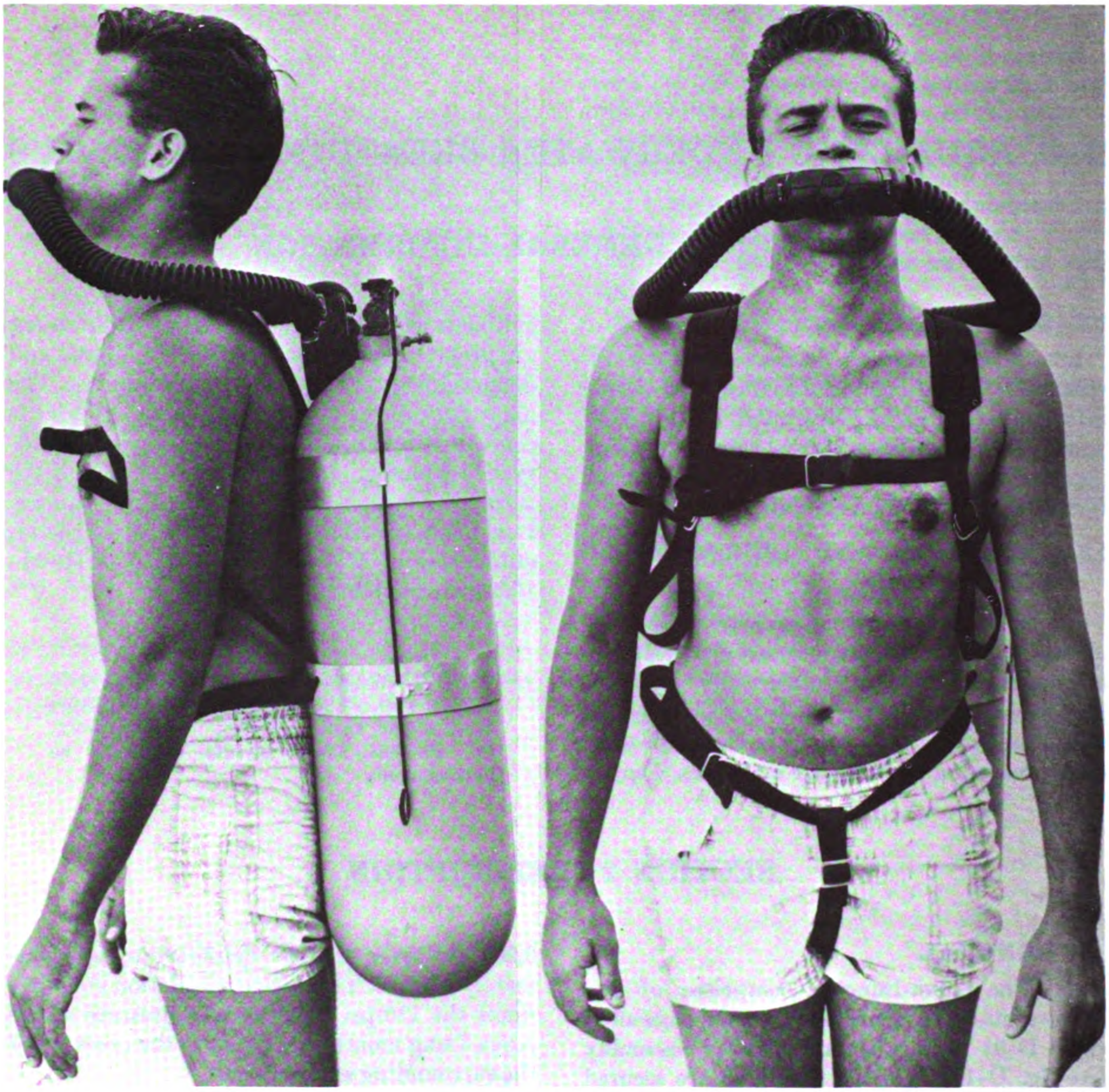


FIGURE D–8.—Aqua-Lung in proper position on diver.

source is connected to the high-pressure port of the demand regulator (demand regulator connected to cylinder-block manifold assembly of Aqua-Lung), the action shown in figure D–11(*a*) occurs: the high-pressure diaphragm is distended, compressing the diaphragm spring and closing the high-pressure seat. The high-pressure seat is positively closed when the pressure exerted by the supply air on the high-pressure diaphragm is 110 psi; at 110 psi, the high-pressure diaphragm spring is sufficiently compressed to permit the high-pressure seat return spring to close the high-pressure seat.

(*b*) *Second-stage regulation.*—The demand regulator box consists of two chambers, separated by the low-pressure diaphragm; the low-pressure chamber is an enclosed airtight area. The water-chamber portion of the box is perforated to permit water from the surrounding environment to enter. The low-pressure diaphragm controls the operation of a horseshoe as shown in figure D–11(*b*), opening the low-pressure valve by overcoming the force exerted by

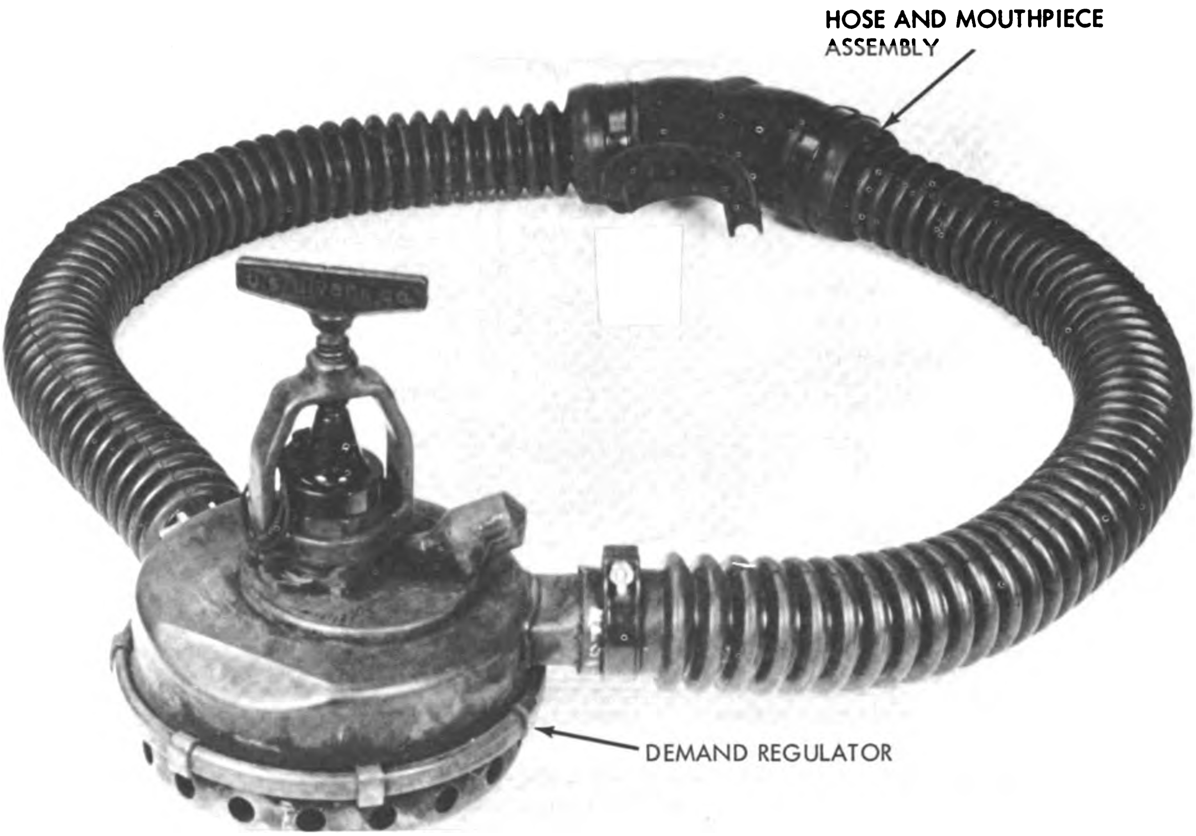


FIGURE D–9.—Demand regulator and hose and mouthpiece assembly

FIGURE D–10.—Air cylinder assembly.

the low-pressure seat spring. If the pressure in the low-pressure chamber is less than that of the surrounding water, the low-pressure diaphragm will deflect inward, and the low-pressure valve will open. The low-pressure valve will remain open until the pressure in the low-pressure chamber is equal to the pressure in the water chamber.

(*c*) *Diver breathing.*—When the diver inhales air from the low-pressure chamber of the demand regulator (see fig. D–11(*b*)), a partial vacuum is created in the low-pressure chamber, and the low-pressure diaphragm deflects inward; the low-pressure diaphragm forces the horseshoe to open the low-pressure valve, admitting enough air to balance the pressure of the surrounding water acting on the water-box side of the low-pressure diaphragm. The low-pressure diaphragm will then return to the normal (balanced) position, and the low-pressure seat spring will close the low-pressure valve (see fig. D–11(*c*)).

2.4 *Mouthpiece and Breathing-Tube Assembly.*—The breathing tube from the low-pressure

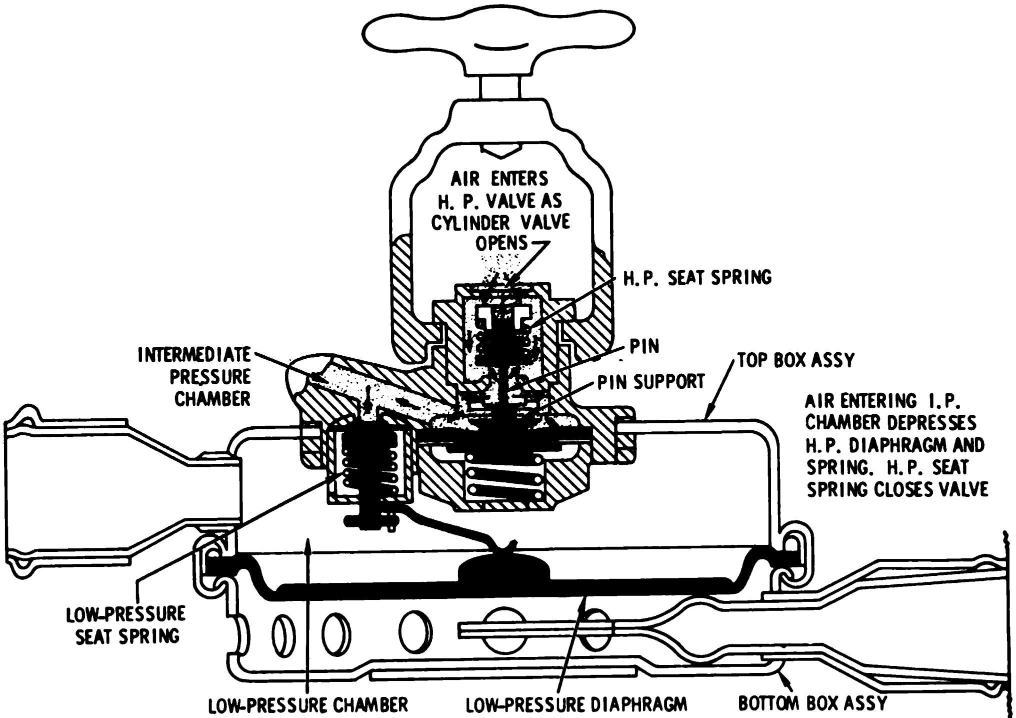


FIGURE D11–(*a*).—Demand-regulator schematic—high-pressure air entering intermediate-pressure area.

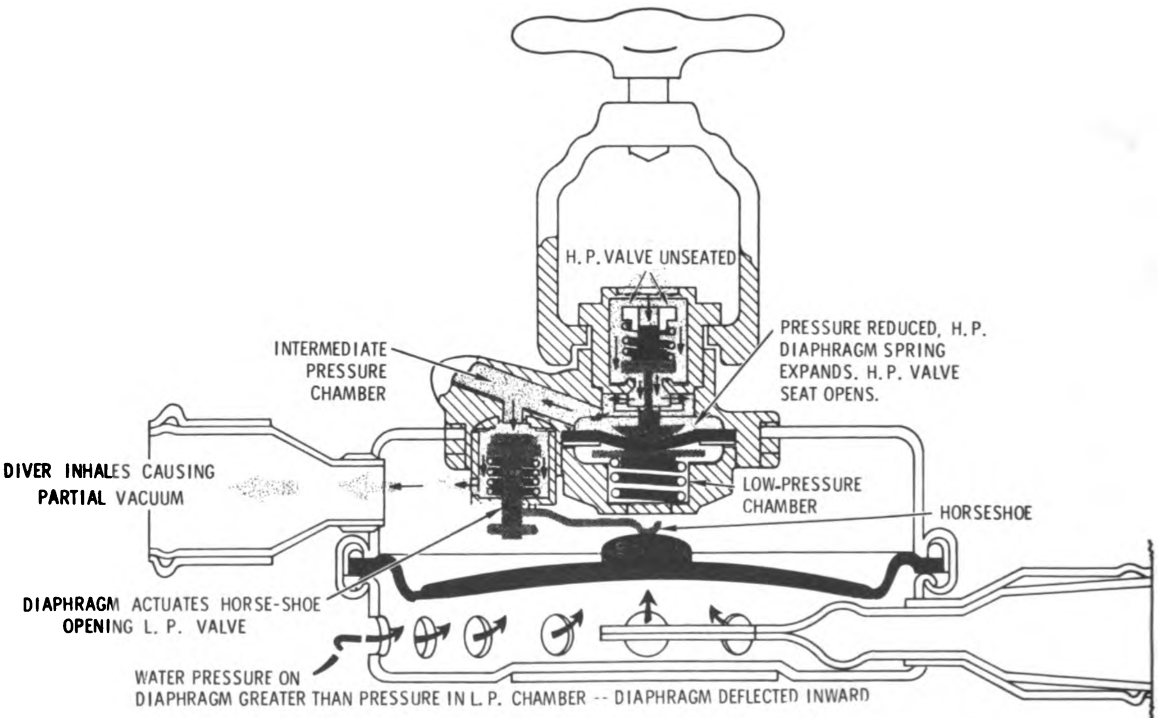


FIGURE D–11(*b*).—Demand-regulator schematic—diver inhaling air.

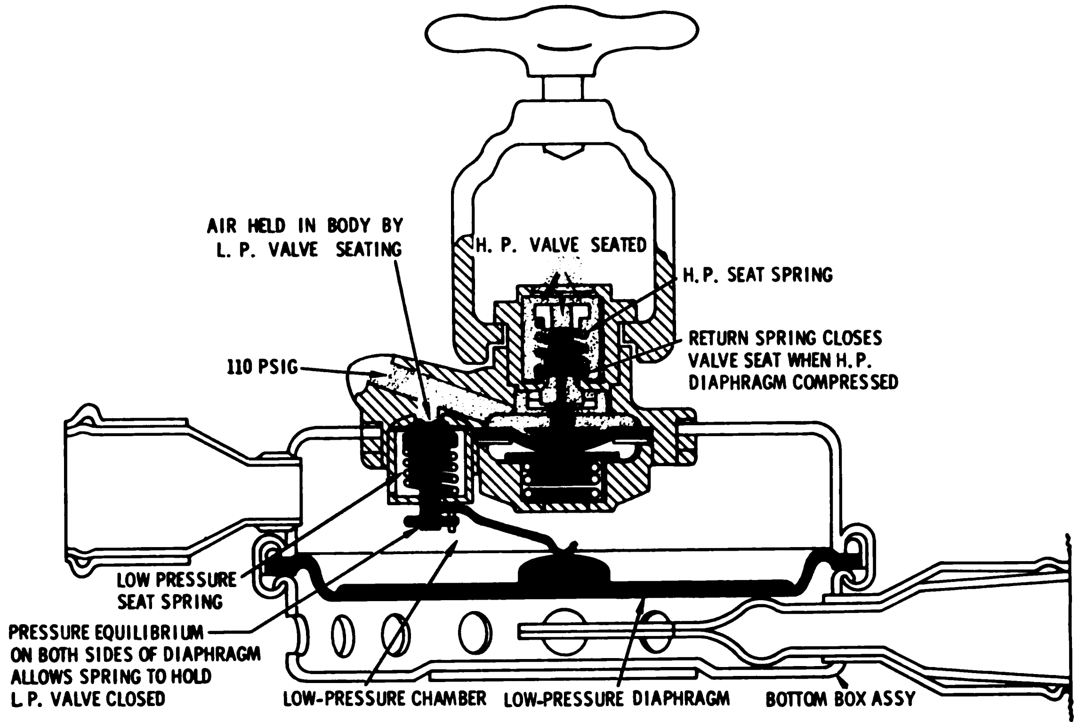


FIGURE D-11(c).—Demand-regulator schematic—first and second stages of regulator in static (balanced) configuration.

chamber of the demand regulator terminates in a mouthpiece T; the breathing tube supplies air through the opening of the split-passage mouthpiece. There are two one-way valves (flapper check valves) in the breathing-tube mouthpiece. During inhalation, the valve in the inhalation side of the mouthpiece opens to allow air to flow to the diver. During exhalation, this valve closes, and the valve in the exhalation side of the mouthpiece opens to allow exhaled air to flow through the exhalation hose to the exhalation tube, and then into the opening of the demand regulator box. The one-way valve in the exhaust tube permits the air to escape, but prevents water from entering the exhaust tube.

2.5 *Cylinder-Block Manifold Assembly* (see fig. D-10).—The cylinder-block manifold assembly consists of a shutoff valve, an air-reserve valve, and an elbow plug assembly. The shutoff valve controls the application of full air-cylinder pressure to the demand regulator. Thin, metallic safety disks (one for each air cylinder) are installed in the cylinder-block manifold assembly, and are designed to rupture at 3,900-psi air-cylinder pressure, providing a safety factor to prevent air-cylinder damage from excessive pressures.

(*a*) *Air-reserve valve.*—The air-reserve valve is built into an elbow in the cylinder-block manifold assembly that connects one of the air cylinders to the shutoff valve. The air-reserve valve serves as a warning and a safety device for the diver. A reserve supply of air is conserved in one of the air cylinders by the air-reserve valve for use by the diver when the main supply of air is nearly exhausted. The pressure in the reserve air cylinder is held at 500 psi as the diver expends the air in the other air cylinder. When the pressure drops below 500 psi, the diver will experience difficulty in breathing; this signal warns the diver that only a fraction of the original air supply remains. The diver can then open the air-reserve valve by pulling down on the pull rod (see fig. D-10) on the side of the left air cylinder.

The air-reserve valve is a flow-check valve with a manual override. As long as the absolute pressure in the air cylinder to which the air-reserve valve is attached remains above 500 psi, flowing air opens the air-reserve valve. When the air-cylinder pressure drops below 500 psi, a spring forces the flow check against a port orifice, shutting off the flow of air from the cylinder. The pressure in this cylinder will then remain at 500 psi, because no air is then being taken from that air cylinder, while the pressure in the other air cylinder continues to drop during diver breathing.

When the diver desires to use the reserve air supply, he opens the air-reserve valve by pulling on the rod described above. This action rotates the valve slide lever one-quarter of a turn. This rotation advances a plunger pin, and pushes the flow check off the orifice against the action of the 500-psi spring. The reserve air from the air cylinder which has been held at 500 psi then flows into the other air cylinder until the pressure equalizes. Because the plunger pin continues to hold the flow check open, the entire reserve supply becomes available to the diver.

WARNING

When the diver experiences difficulty in breathing, indicating that air-cylinder pressure has dropped below 500 psi and it is time to operate the air-reserve valve, he should immediately stop whatever he is doing, and open the air-reserve valve by pulling down on the pull rod on the side of the left air cylinder (see fig. D–10). Normal breathing can then be resumed; however, ascent to the surface should be started immediately because the reserve air supply is only a fraction of the original air supply.

(*b*) *Shutoff valve.*—The shutoff valve in the cylinder-block manifold assembly is used to close or open the passages between the air cylinders and the cylinder-block manifold assembly. Two turns or less of the handle on the shutoff valve fully opens (counterclockwise) or closes (clockwise) the valve. Counterclockwise rotation of the valve handle retracts a disk assembly from the manifold connector T-assembly top port, permitting air to flow from the air cylinders.

2.6 *Air cylinders.*—The compressed-air cylinders for the Aqua-Lung are preaged aluminum cylinders, with a working pressure rating of 3,000 psi and a proof pressure rating of 5,000 psi. Each cylinder has a nominal internal volume of 725 cubic inches. When charged to 3,000 psi, the two air cylinders contain a total of approximately 170 cubic feet of free air. Port threads for attachment to the cylinder-block manifold elbows have a straight thread and an O-ring packing seal.

SECTION 3 INSTALLATION

3.1 UNPACKING

3.2 The Aqua-Lung is packed assembled, and is contained in a single shipping carton; retain carton and packing for future use in storage and reshipment. Normal care should be taken in removing the equipment from the packing carton; the carton containing the equipment should not be subjected to undue heat or misuse during handling and storage.

3.3 INSPECTION OF EQUIPMENT

3.4 Remove regulator and air cylinders from carton, and proceed as follows:

(*a*) Visually check regulator and harness for assembly as shown in figure D–16.

(*b*) Attach the air-reserve pull rod (see fig. D–10) to the air-reserve valve.

(*c*) Fill air cylinders with air as instructed in paragraph 3.6.

(*d*) Connect a 0- to 3,000-psi pressure gage to cylinder valve; open shutoff valve just long enough to obtain a reading on the gage of the pressure in the air cylinders, close shutoff valve, and remove pressure gage. If pressure reading indicates that air cylinders are charged (approximately 3,000 psi), proceed to next paragraph; if not fully charged, continue charging as instructed in paragraph 3.6.

3.5 Install demand regulator as follows:

(*a*) Connect demand regulator to valve assembly on cylinder-block manifold assembly. While tightening the air-yoke screw, check to make sure that the O-ring (29, fig. D–18) is in place and that both ends of the breathing hose are pointing upward (as shown in fig. D–8; when Aqua-Lung is installed on diver, air-breathing hoses should come up from demand regulator; air-yoke screw away from diver).

(*b*) Open shutoff valve on cylinder-block manifold assembly; there shall be no air leakage. Check connections with leak test compound, Military Specification MIL–L–25567, or equivalent.

(*c*) If the system is leaking air in step (*b*), close the shutoff valve, and breathe out all air that has flowed into the demand regulator. This is necessary because high-pressure air in the demand regulator will make it difficult to remove the demand regulator from the cylinder-block manifold assembly. After removing the demand regulator, repeat the connection procedure of the demand regulator to the cylinder-block manifold assembly as described in steps (*a*) and (*b*). Make sure that the O-ring packing (29, fig. D–18) is not nicked, cocked, or twisted when tightening components. The yoke screw (4, fig. D–19) need not be extremely tight since the O-ring packing (29, fig. D–18) makes the pressure seal.

(*d*) Insure that the air-reserve valve is fully closed with the pull rod in the extreme up position.

(*e*) The Aqua-Lung is ready for use after completion of the steps in this and the previous paragraphs.

3.6 RECHARGING AIR CYLINDERS

To charge the air cylinders, proceed as follows:

WARNING

Do not charge the air cylinders with any gas but air; death may result from breathing other gases.

(*a*) Pull the air-reserve valve pull rod down; the air-reserve valve must be open when recharging the air cylinders to permit left air cylinder to be charged.

(*b*) Connect a filler and gage attachment to a source of pure compressed air.

(*c*) Remove the demand regulator from the cylinder-block manifold assembly, and connect the yoke fitting of the filler and gage attachment to the cylinder-block manifold assembly at point from which demand regulator was removed.

(*d*) Open the shutoff valve on the cylinder-block manifold assembly.

(*e*) Open the supply valve from the external air-pressure supply just enough to charge the air cylinders slowly; continue charging the air cylinders until the pressure gage indicates 3,000 psi (or whatever lower pressure is available or desired).

NOTE

The charging process generates heat which causes the air in the air cylinders to expand, giving a false reading at room temperature; top off air cylinders to obtain a full charge as follows:

(*f*) Close the external supply valve and the shutoff valve on the cylinder-block manifold assembly. Allow the air cylinders to cool at room temperature for approximately 2 hours; then reopen valves and resume charging.

(*g*) Continue charging slowly until air-cylinder pressure again reaches 3,000 psi; then, turn off the external supply valve and the shutoff valve on the cylinder-block manifold assembly. Open the bleed valve on the external air-pressure source to remove pressure in line to cylinder-block manifold assembly (so external charging line can be disconnected).

(*h*) Disconnect the pressure gage and filler attachment from the cylinder-block manifold assembly.

NOTE

To accomplish a complete recharge, including topping off, in one operation, submerge the air cylinders in cool water while filling. Keep the water slightly below ambient temperature.

WARNING

The air-reserve valve pull rod must be down, opening the air-reserve valve, when recharging the air cylinders; otherwise, the left air cylinder will not be recharged, reducing the total two-tank air supply, and providing NO reserve air supply.

The air cylinders shall be charged with compressed air only. Attempting to charge with oxygen may produce an explosion during charging; breathing oxygen in deep water can be fatal to a diver.

SECTION 4 OPERATION

4.1 GENERAL

4.2 Prior to using the Aqua-Lung, check that the equipment has been charged with air and assembled as instructed in section 3. If the equipment is satisfactory, proceed with the following steps to use the Aqua-Lung:

4.3 INSTALLING ON DIVER

(*a*) Strap air cylinders on back of diver, with demand regulator placed even with the shoulder blades, so that head of diver, when bent backward, does not touch the top of the demand regulator.

(*b*) Fasten chest strap and belt with quick-release loop as shown in figure D–12 so that the equipment can be quickly disconnected and removed from the diver without any difficulty if the need should arise.

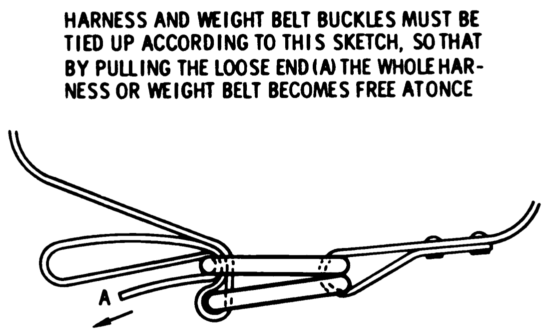


FIGURE D–12.—Quick-release loop.

(*c*) Tighten the harness with the equipment in position of steps (*a*) and (*b*).

(*d*) Insert mouthpiece into mouth, and grip firmly with the teeth, with lips completely closed over the mouthpiece ridge. Open the air shutoff valve, and inhale two or three times to make sure that the equipment is operating.

4.4 TESTING UNDER WATER

(*a*) With Aqua-Lung installed on diver as described in paragraph 4.3, place a swim mask over the eyes and nose.

(*b*) Enter the water, and submerge just beneath the surface.

(*c*) Inhale and exhale a few times to make sure the demand regulator is operating properly. During inhalation, fresh air should flow into the mouthpiece, and during exhalation, fresh air flow should cease and exhaled air should pass freely out of opposite side of breathing tube.

(*d*) Have observer check cylinder-block manifold assembly, shutoff valve, demand regulator, and breathing tubes for air leaks; there should be none. Leaks should be eliminated before using the equipment in diving operations in order to gain maximum use of the available air supply.

4.5 REGULATING BUOYANCY

Buoyancy of the diver varies according to his lung capacity, the density of his body, the density of the water, and the buoyancy of the Aqua-Lung. Regulating the buoyancy of the diver while he is wearing the equipment is very important if equilibrium is to be maintained at all depths and diver attitudes (angles). An adjustable weight belt should be worn by the diver. The diver must determine by experiment the amount of ballast to be added to the adjustable weight belt to counterbalance his own buoyancy plus the buoyancy of the equipment. The amount of ballast will vary from diver to diver, but will generally range from 2 to 9 pounds in sea water. The diver should start diving operations with a little excess ballast because the buoyancy of the equipment will increase as the air supply is used. Additional weight over equilibrium ballast equal to half the weight of air carried per air cylinder is a good general rule. With full air cylinders, the diver and equipment are less buoyant than with empty cylinders; therefore, it is easier to descend with full air cylinders (less buoyant) and easier to ascend with empty cylinders (more buoyant) when the air supply has been used.

4.6 CLEARING WATER

Occasionally water enters the mouthpiece of the Aqua-Lung, either by seepage around the mouth or by leakage at some other point. To eject small amounts of water, lower the left shoulder, and blow into the mouthpiece. The inhalation breathing tube comes over the right shoulder from the demand regulator to the mouthpiece, and the exhalation breathing tube goes over the left shoulder to the demand regulator. To remove water from the inhalation tube, roll from right to left so that the water runs into the exhalation tube; then, blow into the mouthpiece to eject the water through the exhaust breathing tube and exhaust valve.

4.7 OPERATING PRECAUTIONS

(*a*) Be familiar with and observe the applicable diving safety precautions specified in the U.S. Navy Diving Manual.

(*b*) Do not restrict your breathing or hold your breath to conserve the air supply. Breathe normally at all times, particularly during ascent.

WARNING

Holding the breath during ascent can produce a fatal air embolism.

(*c*) Practice water-clearing procedures of paragraph 4.6 in shallow water until the procedure becomes automatic and completely effective.

(*d*) After the air-reserve valve pull rod is pulled (opening the air-reserve valve), reserve air from left air cylinder will flow into relatively empty right air cylinder until pressure in both is equalized; this provides only about 300 psi in both cylinders. When it has become necessary to turn on the reserve air supply, discontinue underwater operations, and ascend to the surface immediately.

(*e*) If for some reason it is necessary to delay ascent until all air supply is exhausted, it is possible to cope with this emergency situation, even though it is serious, if the following items are noted:

1. DO NOT PANIC.
2. When breathing becomes difficult, the pressure remaining in the air cylinders is almost equal to the pressure of the water at the depth of the diver.
3. Ascend at once, breathing as lightly as possible, but do not hold breath.
4. For every 33 feet of ascent, the diminishing water pressure will release about 0.8 cubic foot of air from the air cylinders. With care, this additional free air will provide enough breathing air for the diver to reach the surface.

4.8 OPERATOR MAINTENANCE

There are no routine operator maintenance items applicable to the Aqua-Lung. With reasonable care, the equipment does not require service at the operator level. The operator should visually examine the equipment prior to and after each use to make sure that the hoses and mouthpiece have not become torn or separated from each other and the demand regulator during use, that the demand regulator is securely attached to the cylinder-block manifold assembly, and that the air cylinders and attached hardware are secure and undamaged. The operator should also check the air supply in the air cylinders prior to use.

SECTION 5 TROUBLESHOOTING

5.1 GENERAL

5.2 Malfunctions with the equipment will usually lead directly to the area of trouble causing the malfunction: for example, a torn air tube, disconnected mouthpiece, depleted air cylinder, etc. If the malfunction does not yield to such simple trouble localization methods, refer to table D-1 for troubleshooting data applicable to more complex malfunctions.

TABLE D-1.—*Troubleshooting data*

Trouble	Probable cause	Remedy
	Demand Regulator Assembly (see fig. D-19)	
1st-stage air leak (after inhaling, hissing starts in about 1 second).	Damaged seat assembly (12)	Reface or replace seat assembly.
	Damaged nozzle (16)	Reface or replace nozzle.
2d-stage air leak (after inhaling, hissing starts immediately).	Scratched orifice in body (34)	Reface scratched surface.
	Damaged seat in seatholder and disk assembly (33).	Replace seat holder and disk assembly.
Hard to breathe	Pressure regulating screw (17) not adjusted properly.	Refer to par. 6-7(*i*); turn in clockwise direction to decrease pressure.
	Hose and mouthpiece assembly improperly assembled.	Reassemble per exploded view (components 37 through 42, fig. D-19).
Water leak	Pin hole in hose (38)	Replace defective hose.
	Diaphragm (24) not in seat properly (cocked).	Reassemble properly.
	Ring (3) loose	Tighten ring.
	Cylinder Block Manifold Assembly (see fig. D-18)	
Air leak	Bonnet (25) loose or damaged	Tighten or replace bonnet.
	Washer (26) not tight around stem (27)	Replace washer; tighten bonnet (25).
	Loose or bad washer (21)	Replace washer; tighten plug (19).
Reserve fails to operate	Stem (7) improperly positioned	Disassemble reserve side of valve, and place lever (3) in proper position.
	Disk and retainer assembly (10) has damaged seat.	Replace defective component.
Valve handle fails to operate	Slot in stem (27) sheared off	Replace stem.

SECTION 6 MAINTENANCE

6.1 PREVENTIVE MAINTENANCE

6.2 The Aqua-Lung is a rugged unit, but it may deteriorate unless it receives reasonable care. Keeping the regulator and breathing-tube assembly clean, especially after use in sea water, will minimize the necessity for corrective maintenance. Observe the following procedures:

(*a*) Always detach the regulator from the air cylinders for storage.

(*b*) After using the apparatus in sea water, clean the regulator by rinsing it thoroughly in warm, fresh water.

(*c*) Never allow water to enter the high-pressure connection of the regulator.

(*d*) Clear inhalation and exhalation hoses, mouthpiece, and exhaust valve as follows (see fig. D–19): Disconnect clamp (37) from top box assembly (2), and remove hose (38) from top box assembly (2) and pour fresh water through the hose, mouthpiece, and exhaust valve. Repeat at least three times to insure that hose, mouthpiece, and exhaust valve are thoroughly rinsed.

(*e*) Hang the regulator up by the yoke to dry.

(*f*) Inspect the rubber exhaust valve (35, fig. D–19) occasionally, to see that salt deposits do not become lodged between it and the nozzle of the bottom box (36).

(*g*) Rinse the air cylinders and high-pressure manifold thoroughly with fresh water to remove all traces of salt deposits.

(*h*) Store the cylinder assembly carefully when not in use.

(*i*) Although compressed air normally does not show signs of contamination after storage for long periods, it is advisable to discharge the cylinders and recharge them after 1 year in storage.

6.3 REPAIR

CAUTION

When a vise is specified in the following procedures, use a vise that has soft jaws of copper or other nonmagnetic material to insure that the nonmagnetic characteristics of the detail parts of the equipment covered in this manual are not changed.

6.4 DEMAND REGULATOR (see fig. D–19)

Overhaul of the demand regulator requires a source of oil-free compressed air. The compressed-air cylinders are recommended for the source of air to be used in the following instructions (also refer to WARNING preceding Parts List).

6.5 DISASSEMBLY PROCEDURE—DEMAND REGULATOR

(*a*) Remove the four hose clamps (37 and 39), and pull off the neoprene hose (38) at inlet and exhaust ports. Then remove valve disk support (40) and rubber disk (41) from mouthpiece T (42).

(*b*) Place regulator in vise by gripping edge of valve main body (34).

(*c*) Using a screwdriver as a pry, remove the seven box clips (1). Key both parts of the regulator box (2 and 36) with a nonmetallic scribe so that the box clips can be assembled in the same positions. Remove bottom box assembly (36) and diaphragm (24).

(*d*) Inspect exhaling valve (35) and, if it needs replacing, remove through exhaust port on bottom box (36).

(*e*) Bolt body wrench (5, fig. D–20) to a workbench, and place body (34, fig. D–19) in body wrench. Using wrench (4, fig. D–20), unscrew ring (3, fig. D–19) with a counterclockwise motion, and remove top box assembly (2). The valve main-body assembly is now ready to be disassembled.

(*f*) For safety purposes, the hex nut (25) has been cemented and counterpunched. Since it is impossible to unscrew this nut, cut the threaded rod of seat holder and disk assembly (33) with a pair of cutting pliers. Then remove the horseshoe (27). Unscrew the two screws (28) and remove lock supports 1 and 2 (29 and 30). Unscrew the seat holder (31) using a 5/8-inch offset box wrench, remembering that the seat holder is still spring loaded. Replace seat holder (31), washer (26), and nut (25). After overhaul and inspection, reassemble in reverse order.

NOTE

Be sure to use litharge cement and counterpunch nut and disk stem (25 and 33). Another

way to secure this assembly is to file sideways almost half of the threaded end of disk stem (33). After the nut is well tightened, bring one of the sides of the hex nut (25) exactly parallel with the filed side of disk stem and pinch with nonmagnetic claw pinchers.

(*g*) Remove pressure-regulating screw (17) remembering that the screw is spring loaded; remove spring (18).

(*h*) Unscrew spring retainer (19). This releases spring pad (20), diaphragm gasket (21), diaphragm (22), and gasket (23).

(*i*) Pull pin support (14) away from pin (15); then, remove gasket (13) from high-pressure valve assembly.

(*j*) Turn valve main body (34) over and replace in vise; then, unscrew and remove high-pressure valve assembly from yoke (5).

(*k*) Using circlip pliers (3, fig. D–20), remove circlip (8, fig. D–19), noting that circlip is spring loaded. Remove sintered filter (9), spring block (10), spring (11), and seat assembly (12).

(*l*) Unscrew yoke screw (4) from yoke (5). The regulator is now completely disassembled and ready for overhaul and inspection.

6.6 OVERHAUL PROCEDURE—DEMAND REGULATOR

(*a*) Carefully inspect corrugated hoses (38), diaphragm (24), and exhaust valve (35) for leaks. See that no salt has crystallized in any of these parts, particularly in the folds of the exhaust valve.

(*b*) Clean corrosion from metallic parts by polishing with aluminum oxide abrasive cloth, Federal Specification P–C–451. Replace all parts that are corroded to such an extent as to require excessive polishing. Replace all fiber washers, gaskets, and O-rings at each disassembly for repair or overhaul.

CAUTION

Do not allow fluids to enter top of high-pressure valve assembly.

6.7 ASSEMBLY AND TEST PROCEDURE—DEMAND REGULATOR

(*a*) Place nozzle (16) in a vise, with wrench flats against soft jaws of vise.

(*b*) Insert seat assembly (12) and spring (11) in high-pressure block assembly guide (1, fig. D–20); then, place assembly guide against nozzle (16, fig. D–19) alining seat assembly (12) with cavity in nozzle (16).

(*c*) Place spring block (10), filter (9), and circlip (8) over parts in assembly guide (positioned in step (*b*)), and push parts through assembly guide into nozzle (16) with a ½-inch-diameter wooden dowel. Make sure parts go in all the way into nozzle (16), and that circlip (8) expands into retaining groove in nozzle (16).

(*d*) Attach yoke screw (4) to yoke (5), and place high-pressure valve assembly through the hole in yoke (5), and test for leakage by attaching to cylinder block (fig. D–18). Apply oxygen systems leak test compound, Military Specification MIL–L–25567A(ASG), to the valve assembly; bubbles in the test compound indicate escaping air. If there is leakage, replace high-pressure valve assembly with a spare and retest as above.

(*e*) Deleted.

(*f*) Remove high-pressure valve and yoke from the cylinder block and attach to regulator main body (34, fig. D–19), using gasket (13) as a seal. While holding body (34) in body wrench (5, fig. D–20), tighten the valve down snugly, with an adjustable wrench, 12 inches long.

NOTE

After tightening, check to see that yoke (5, fig. D–19) swivels freely in assembly; then, replace body (34) in body wrench (5, fig. D–20) to facilitate reassembly.

(*g*) Place pin (15, fig. D–19) and pin support (14) into end of valve assembly body. Lay diaphragm (22) and diaphragm gasket (21) into place, and secure edges into undercut provided by running the smooth round point of a metal or wooden rod with a half-inch diameter around circumference. Place spring pad (20) on diaphragm (22); then screw retainer (19) into regulator body (34) until it seats hard against diaphragm gasket (21).

(*h*) Drop spring (18) into spring retainer (19), and screw pressure-regulating screw (17) down over spring (18) into threaded hole provided in spring retainer (19).

(*i*) Adjustment of regulating screw (17) is very critical, and should be done with the utmost care. Connect assembly, complete to this point, to a fully charged cylinder block. Attach a

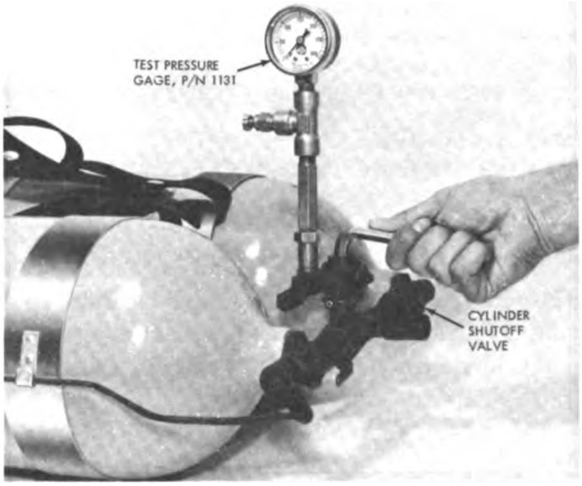


FIGURE D–13.—Adjustment of regulator—first stage.

pressure gage (2, fig. D–20) to the nozzle recess of regulator body. Open cylinder shutoff valve (see fig. D–13), and, with an allen wrench, adjust the adjusting screw for a reading of 110 ± 5 psi on the pressure gage. Close the shutoff valve and open the bleed valve to release the pressure. Close the bleed valve and again open the shutoff valve. See that the same pressure is indicated. This procedure should be followed at least three times. Keep gage in place for at least 1 minute each time tested to make sure that there is no air leakage from the high-pressure valve. If the pointer creeps higher, the high-pressure valve assembly (8 through 23) is defective and must be replaced.

(*j*) Replace assembly in body wrench (5, fig. D–20).

(*k*) Place seat holder and disk assembly (33, fig. D–19) into the hole provided in body (34), and place spring (32) over threaded shaft of disk assembly (33); then, place seat holder (31) over threaded shaft of disk assembly (33), and screw into hole provided in body (34). Before inserting screws (28), put one or two drops of sealant (refer to table D–2) in the holes. Insert screws (28) through supports (29 and 30) and then into the sealant-treated holes; tighten down the screws to secure seat holder (31).

CAUTION

Treating the holes with sealant serves to safety the screws (28). Do not fail to observe this procedure; otherwise, vibration could loosen the screws (28), and the supports (29 and 30) impairing the functioning of the horseshoe (27).

TABLE D–2.—*Sealant*

Formula:
Loctite sealant, Grade A.
Method of application:
Eyedropper.
Specification:
No known Government specification.
Supply sources:
American Sealant Co., Hartford, Conn.

(*l*) Seat horseshoe (27) in position on disk shaft (33) and place washer (26) on disk shaft (33) in the indentation of the horseshoe (27); then, screw nut (25) on disk shaft (33). Check travel of horseshoe extremities. There should be a minimum travel of 0.275 inch. If horseshoe does not travel 0.275 inch, bend both extremities slightly until 0.275 inch is met.

NOTE

Be sure to use litharge cement and counterpunch the nut (25) and the disk shaft (33) (refer to step (*f*), par. 6.5).

(*m*) Connect entire assembly so far assembled to air cylinders as instructed in step (*i*), and, with shutoff valve fully opened, actuate horseshoe assembly (27) several times. Very light finger pressure should start the air immediately. Upon removing the fingers, all flow of air should stop. If air is detected escaping, replace seat holder (31), and repeat steps (*h*) and (*i*), preceding.

(*n*) Remove assembly from cylinder block and replace in a vise or body wrench (5, fig. D–20).

(*o*) Place gasket (23, fig. D–19) evenly on body (34), and place top box assembly (2) on top of gasket. Note that box assembly and regulator body are keyed for proper alinement.

(*p*) Lubricate ring (3) with lubricant listed in table D–3.

(*q*) Thread ring (3) down over regulator body (34), and secure top box assembly (2) to regulator body very tightly. Use wrench (4, fig. D–20) to tighten ring (3, fig. D–19); the ring pressing the box assembly against gasket (23) and body (34) shall make a watertight and airtight seal.

Figure D–14.—Locating low-pressure diaphragm with respect to horseshoe extremities.

(*r*) Position diaphragm (24) on top box assembly (2) so that the two actuating extremities of horseshoe assembly (27) will center on the contact surfaces that protrude from diaphragm (24). (See fig. D–14.)

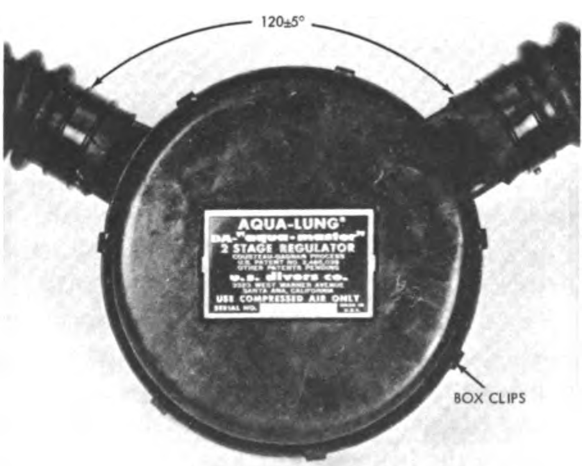


Figure D–15.—Box clip and port orientation—demand regulator.

Table D–3.—*Lubricant No. 2*

Formula:
5 parts petrolatum, 5 parts parawax, 1½ parts graphite.
Method of application:
Heat compound to 210° F. and dip part into compound.

(*s*) Place bottom box assembly (36) so that the outlet port is 120 degrees from the inlet port (fig. D–15). Make sure that the exhaling valve (35) has been inserted properly in the outlet port on the bottom box (36).

(*t*) Remove assembly from vise (or body wrench), and attach again to cylinder block for test. Open shutoff valve.

(*u*) Apply pressure with hand to bottom box (36) to hold demand regulator in semiassembled condition (without box clips (1) in place). Breathe several times through the mouthpiece and listen for air leakage at the mouthpiece. In case of leakage, either the low-pressure seat is defective or the pressure in the intermediate-pressure chamber is too high. If breathing is extremely difficult, the diaphragm (24) is not properly positioned with respect to the horseshoe extremities.

(*v*) Return assembly to vise; then, hook box clips (1) in positions marked when disassembled (also, see fig. D–15). Seven box clips are required. Crimp box clips to assure a very tight fit with even pressure exerted on the diaphragm (24) all around the periphery of the top and bottom box assemblies (2 and 36).

(*w*) Connect assembly to cylinder block and open shutoff valve. Breathe from inlet port, first rapidly and then slowly to check the function of the demand system as a complete unit. Repeat several times. Take a quick deep breath and listen to the port for sounds of air leaking. If air can be heard immediately, it indicates that the low-pressure valve is leaking. If leakage is heard after a short interval, it indicates that the high-pressure valve is leaking. In either case, the entire assembly procedure should be repeated.

(*x*) After satisfactory completion of final test, reassemble mouthpiece T (42) with rubber valve disk (41) and valve disk support (40).

Connect hoses (38) and mouthpiece T (42) to regulator ports with the four hose clamps (37 and 39; 2 each). Hold mouthpiece loosely in fingers and make sure that it orients itself with the nameplate on the regulator. This is approximately the position the mouthpiece assumes when in use. If mouthpiece does not assume position readily, rotate hoses slightly on regulator ports until proper orientation is obtained. The regulator is now completely assembled, tested, and ready for use.

6.8 CYLINDER-VALVE ASSEMBLY (see fig. D–18)

Do not disassemble the cylinder-valve assembly unless it is definitely determined that the assembly is faulty. Under normal operating conditions, the valve assembly can be used for several years without need for overhauling.

6.9 DISASSEMBLY PROCEDURE—CYLINDER VALVE ASSEMBLY

WARNING

Be certain that no pressure exists in either air cylinder before commencing disassembly.

(*a*) Remove harness and aluminum bands (see fig. D–16). Proceed by uncoupling the center unit that houses the shutoff valve from the two assemblies attached to the two air cylinders. Remove the elbow and reserve elbow from the tanks.

CAUTION

Make certain that threads are not damaged during these procedures.

(*b*) Proceed with disassembly of reserve valve by unscrewing nut (1), and removing spring (2).

(*c*) Slide lever (3) and washer (4) off end of stem (7).

(*d*) Unscrew bonnet (5) from elbow (15) and slip out washer (6), stem (7), plunger and pin assembly (8), and spring (9).

(*e*) From other end of reserve valve assembly, unscrew plug (13); remove washer (14), spring (12), washer (11), and disk and retainer assembly (10).

(*f*) Unscrew nut (22), and remove spring (2).

(*g*) Slide valve handle (23) and washer (24) off end of stem (27).

(*h*) Unscrew bonnet (25) from body (30), and remove washer (26) and stem (27).

(*i*) Unscrew seat disk retainer assembly (28).

(*j*) Unscrew the two safety plugs (19), and remove safety disks (20) and washers (21).

(*k*) Remove rubber outlet O-ring seal (29) only if necessary.

6.10 OVERHAUL PROCEDURE—CYLINDER VALVE ASSEMBLY

(*a*) Remove all residual lubricant and sealing compound, and follow same procedure used in step (*b*), paragraph 6.6 (demand-regulator overhaul). Thoroughly clean all parts and dry with blasts of air. Visually inspect all parts for damage. Normally, the only overhaul procedure required for air-valve assemblies will be the necessity for repacking with approved lubricants (listed in table D–4) and resealing with approved sealing compounds (listed in table D–5) and replacing O-rings.

(*b*) Airblast the inside of air cylinders to remove any metal chips that may have accumulated.

6.11 ASSEMBLY PROCEDURE—CYLINDER VALVE ASSEMBLY

(*a*) Replace the two safety disk washers (21), safety disks (20), and safety plugs (19); tighten plugs snugly against disks and washers.

(*b*) Replace rubber O-ring seal (29).

(*c*) Lubricate seat-disk retainer assembly (28) with lubricant listed in table D–4.

(*d*) Replace stem (27), seeing that it sits in the slot of the seat-disk retainer assembly (28).

(*e*) Slip washer (26) down over stem (27), and screw bonnet (25) into body (30) until it bottoms on body shoulder.

(*f*) Place washer (24) on bonnet (25), keeping the two concentric.

(*g*) Apply cement (refer to table D–5) to the inside threads of nut (22) and wipe off excess. Then drop valve handle (23), and spring (2), over stem (27), and tighten nut (22) on threaded portion of stem until it is flush with top of valve handle. Wipe off excess cement.

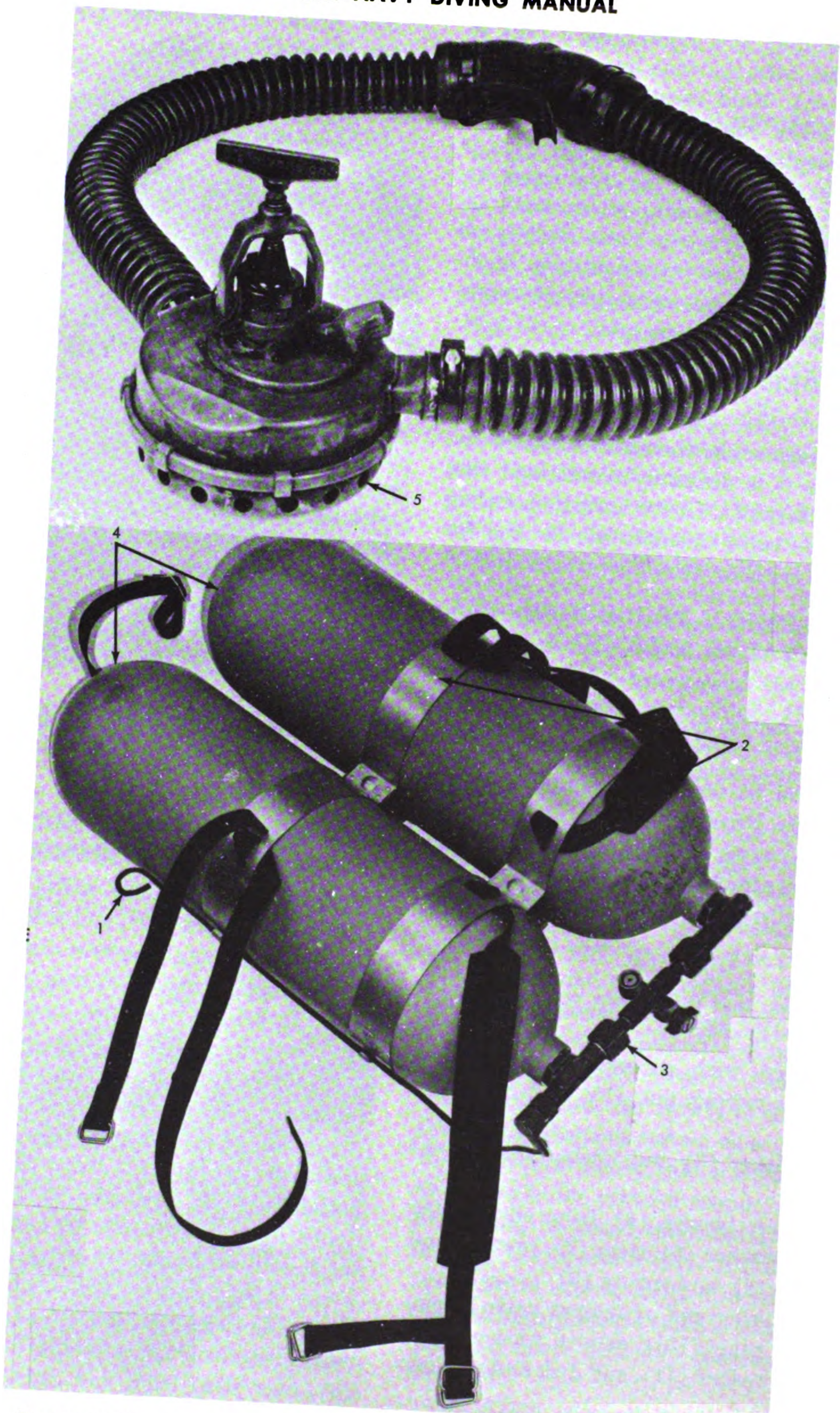


FIGURE D–16.—Aqua-Lung underwater breathing apparatus, part No. 0659–00.

TABLE D–4.—*Lubricant No. 1*

Formula:
Dow Corning Valve Seal "A" Silicone Grease.
Method of application:
No special method required.
Supply sources:
Dow Corning Corp., 228 North La Salle St., Chicago, Ill.

TABLE D–5.—*Sealing compound No. 1*

Formula:
4 grams litharge to 1-cc glycerine.
Method of application:
With brush or knife.
Supply sources:
Glycerine: "Chemically Pure Grade Glycerine," Allen D. Wrisley & Co., Chicago, Ill.
Litharge: Spec. cement grade and must be canary yellow in color and of fine texture, National Lead Co., Chicago, Ill.

(*h*) Assemble reserve valve by first sliding disk and retainer assembly (10), washer (11), and spring (12) into body (15); place washer (14) into elbow (15), and then screw plug (13) into body until it bottoms on elbow shoulder.

(*i*) On other end of reserve valve, place spring (9) into elbow (15).

(*j*) Lubricate V-grooves in plunger and pin assembly (8) generously with lubricant in table D–3. Slide plunger and pin assembly into spring (9), and set stem (7) in large V-groove of plunger and pin assembly.

(*k*) Place washer (6) on stem (7), and screw bonnet (5) into elbow (15) until it seats on inside shoulder of elbow.

(*l*) Place washer (4) on bonnet (5), and place lever (3) over washer (4) in the up or counterclockwise position.

(*m*) Apply cement (refer to table D–5) to the inside threads of nut (1) and wipe off excess. Place spring (2) into lever (3); and screw nut (1) down over threaded portion of stem (7) until nut is flush with lever (3). Wipe off excess cement.

SECTION 7 PARTS LIST

TABLE D–6.—*Lubricant No. 3*

Supply sources:
Petrolatum: "Stanolind Petrolatum, U.S.P. Grade Golden Topaz," Standard Oil Co. of Chicago, Ill.
Parawax: Standard Oil Co. of Ill., Chicago, Ill.
Graphite: "Dixon's No. 635 Flake Graphite," Joseph Dixon Crucible Co., Jersey City, N.J.

7.1 GENERAL

7.2 This parts list illustrates the parts used in the underwater breathing apparatus covered in this manual, with the part numbers in the parts list keyed to the photographs and exploded-view illustrations provided in this parts-list section. All units of the equipment, including major assemblies, subassemblies, and their maintenance parts, are listed in the following breakdown.

WARNING

Replacement parts shall be requisitioned only from Ships Parts Control Center, Mechanicsburg, Pa. Requests shall specify parts to be nonmagnetic.

7.3 SPECIAL TOOLS

Special tools used with the Aqua-Lung during overhaul and repair are shown in figure D–20, and keyed to their related parts list.

Figure and index No.	Part No.	Description	Units per assembly
D–16	0659–00	Breathing apparatus, underwater, Aqua-Lung (FSN S4220–541–7397)	1
	0658–00	Cylinder assembly, air, complete	1
D–16–1	0522–04	Rod, pull, air reserve	1
D–16–2	0808–00	Harness assembly (see fig. D–17 for breakdown)	1
D–16–3	0532–00	Manifold assembly, cylinder block (fig. D–18 for breakdown)	1
D–16–4	0724–00	Cylinder, air	2

Figure and index No.	Part No.	Description	Units per assembly
D–16–5	1062–00	Regulator assembly, demand (see fig. D–19 for breakdown)	1
	(Ref.)	Special tools, Aqua-Lung (see fig. D–20)	Ref.
D–17	0808–00	Harness assembly (see fig. D–16 for NHA)	Ref.
	0808–05	Harness assembly, top	1
D–17–1	0812–54	Strap assembly, left shoulder	1
D–17–2	0812–55	Strap assembly, right shoulder	1
D–17–3	8500–01	Nut	1
D–17–4	8450–06	Washer	1
D–17–5	8370–04	Bolt	1
D–17–6	0808–01	Band, top	1
	0808–06	Harness assembly, bottom	1
D–17–7	0812–51	Belt assembly, waist	1
D–17–8	0812–30	Strap, waist	1
D–17–9	8500–01	Nut	1
D–17–10	8450–06	Washer	1
D–17–11	8370–04	Bolt	1
D–17–12	0812–53	Strap assembly, crotch	1
D–17–13	0802–10	Bar, slide	1
D–17–14	0808–02	Band, bottom	1
	0812–50	Webbing assembly (consists of index Nos. 1, 2, 7, 8, and 12 as a complete set).	1
D–18	0532–00	Manifold assembly, cylinder block (see fig. D–16 for NHA)	Ref.
	0532–01	Elbow assembly, reserve	1
D–18–1	0532–15	Nut, wheel	1
D–18–2	0528–22	Spring	2
D–18–3	0532–03	Lever	1
D–18–4	0532–14	Washer	1
D–18–5	0532–04	Bonnet	1
D–18–6	0502–08	Washer	1
D–18–7	0528–43	Stem	1
D–18–8	0528–45	Plunger and pin assembly	1
D–18–9	0528–19	Spring	1
D–18–10	0528–17	Disk and retainer assembly	1
D–18–11	0517–06	Washer	1
D–18–12	0528–09	Spring	1
D–18–13	0528–10	Plug	1
D–18–14	0518–06	Washer	1
D–18–15	0532–05	Elbow, body reserve	1
	0532–06	Elbow assembly	1
D–18–16	0532–07	Cap, elbow	1
D–18–17	8210–11	Washer, Teflon	1
D–18–18	0532–08	Elbow and tube	1
D–18–19	0532–09	Plug, safety	2
D–18–20	0502–12	Disk, safety	2
D–18–21	0502–50	Washer	2
	0532–10	Valve assembly, shutoff	1
D–18–22	0532–02	Nut, wheel	1
D–18–23	0532–11	Handle, valve	1
D–18–24	0532–14	Washer	1
D–18–25	0532–12	Bonnet	1
D–18–26	0502–08	Washer	1
D–18–27	0528–40	Stem	1
D–18–28	0528–42	Retainer assembly, seat disk	1
D–18–29	8201–12	O-ring	1
D–18–30	0532–13	Body, nipple, and nut assembly	1
D–18–31	8202–14	Packing, O-ring	2

Figure and index No.	Part No.	Description	Units per assembly
D–19	1062–00	Regulator assembly, demand (see fig. D–16 for NHA)	Ref.
D–19–1	1045–05	Clip, box	7
D–19–2	1062–02	Box assembly, top	1
D–19–3	1062–03	Ring	1
D–19–4	1062–04	Screw, yoke	1
D–19–5	1062–05	Yoke	1
	1010–12	Cap assembly, protection	1
D–19–6	8201–12	Packing, O-ring	1
D–19–7	1010–13	Cap, protection	1
	1062–06	Valve assembly, high pressure	1
D–19–8	1000–22	Circlip	1
D–19–9	1062–07	Filter, sintered	1
D–19–10	1062–08	Block, spring	1
D–19–11	1045–10	Spring, high-pressure seat	1
D–19–12	1062–09	Seat assembly	1
D–19–13	8210–03	Gasket	1
D–19–14	1045–03	Support, pin	1
D–19–15	1000–25	Pin	1
D–19–16	1062–10	Nozzle, high pressure	1
D–19–17	1062–11	Screw, pressure regulating	1
D–19–18	1045–04	Spring, diaphragm	1
D–19–19	1062–12	Retainer, diaphragm spring	1
D–19–20	1045–15	Pad, spring	1
D–19–21	8210–01	Gasket	1
D–19–22	1000–29	Diaphragm, high-pressure	1
D–19–23	1000–34	Gasket	1
	(Ref.)	Valve assembly, low pressure	Ref.
D–19–24	1045–19	Diaphragm, low-pressure, neoprene	1
D–19–25	8520–16	Nut, hex	1
D–19–26	8450–15	Washer	1
D–19–27	1045–26	Horseshoe	1
D–19–28	8340–03	Screw	2
D–19–29	1045–24	Support, lock, left	1
D–19–30	1045–23	Support, lock, right	1
D–19–31	1062–13	Holder, seat	1
D–19–32	1045–29	Spring, low pressure seat	1
D–19–33	1062–14	Seat holder and disk assembly	1
D–19–34	1062–15	Body	1
D–19–35	1062–23	Valve, exhaust	1
D–19–36	1062–16	Box, bottom	1
	1129–00	Hose and mouthpiece assembly	1
D–19–37	1128–14	Clamp, nylon, 1¼ inch	2
D–19–38	1128–08	Hose, neoprene	2
D–19–39	1128–15	Clamp, nylon, 1¾ inch	2
D–19–40	1108–03	Support, valve disk	2
D–19–41	1108–02	Disk, valve, rubber	2
D–19–42	1128–02	T-mouthpiece	1
D–20	(Ref.)	Special tools	Ref.
D–20–1	1130	Assembly guide, high-pressure block	1
D–20–2	1131	Pressure gage, test pressure (with adapter)	1
D–20–3	1111	Pliers, circlip	1
D–20–4	1132	Wrench (for tightening dented ring)	1
D–20–5	1133	Body wrench	1

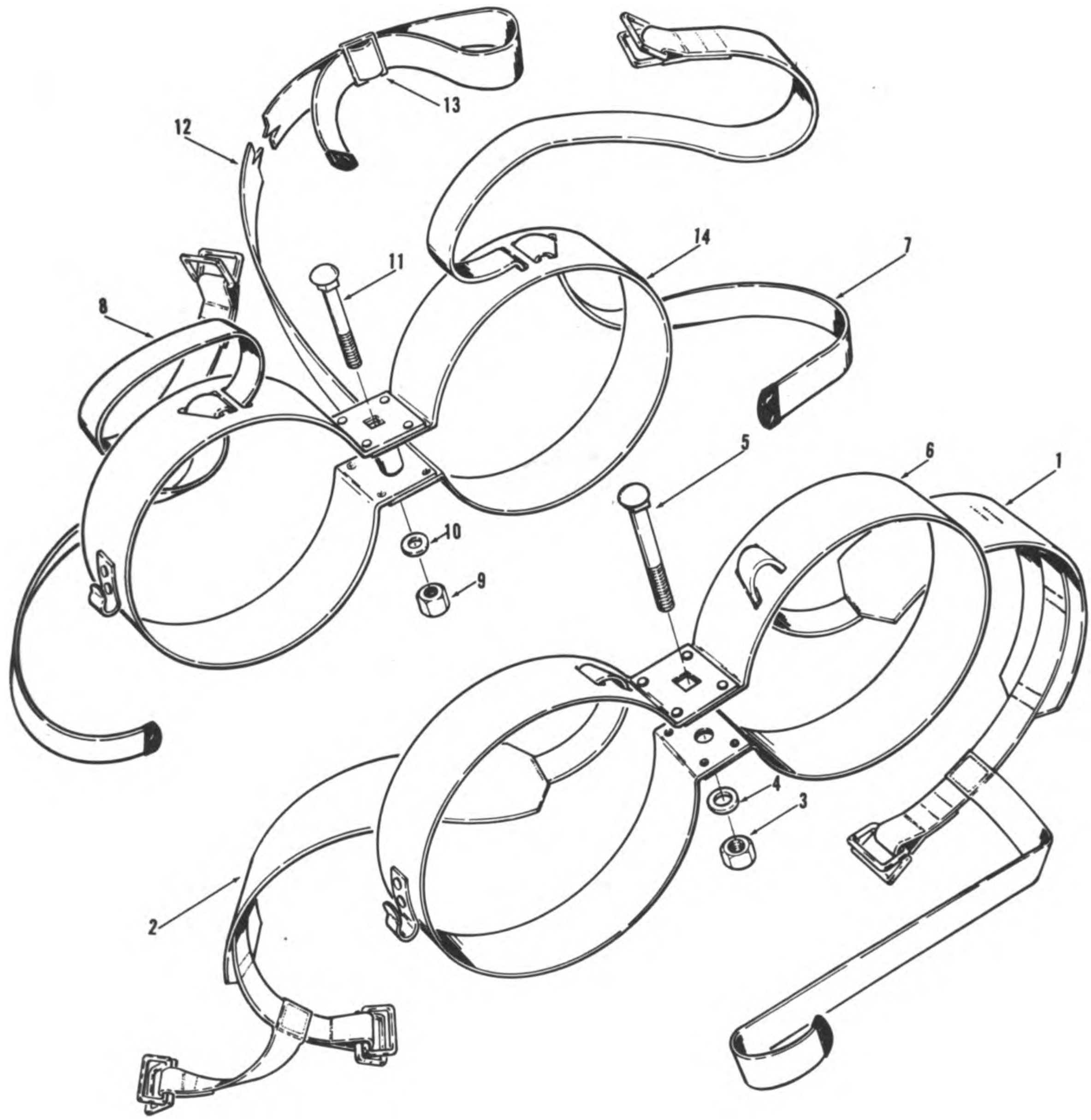


Figure D–17.—Harness assembly—exploded view.

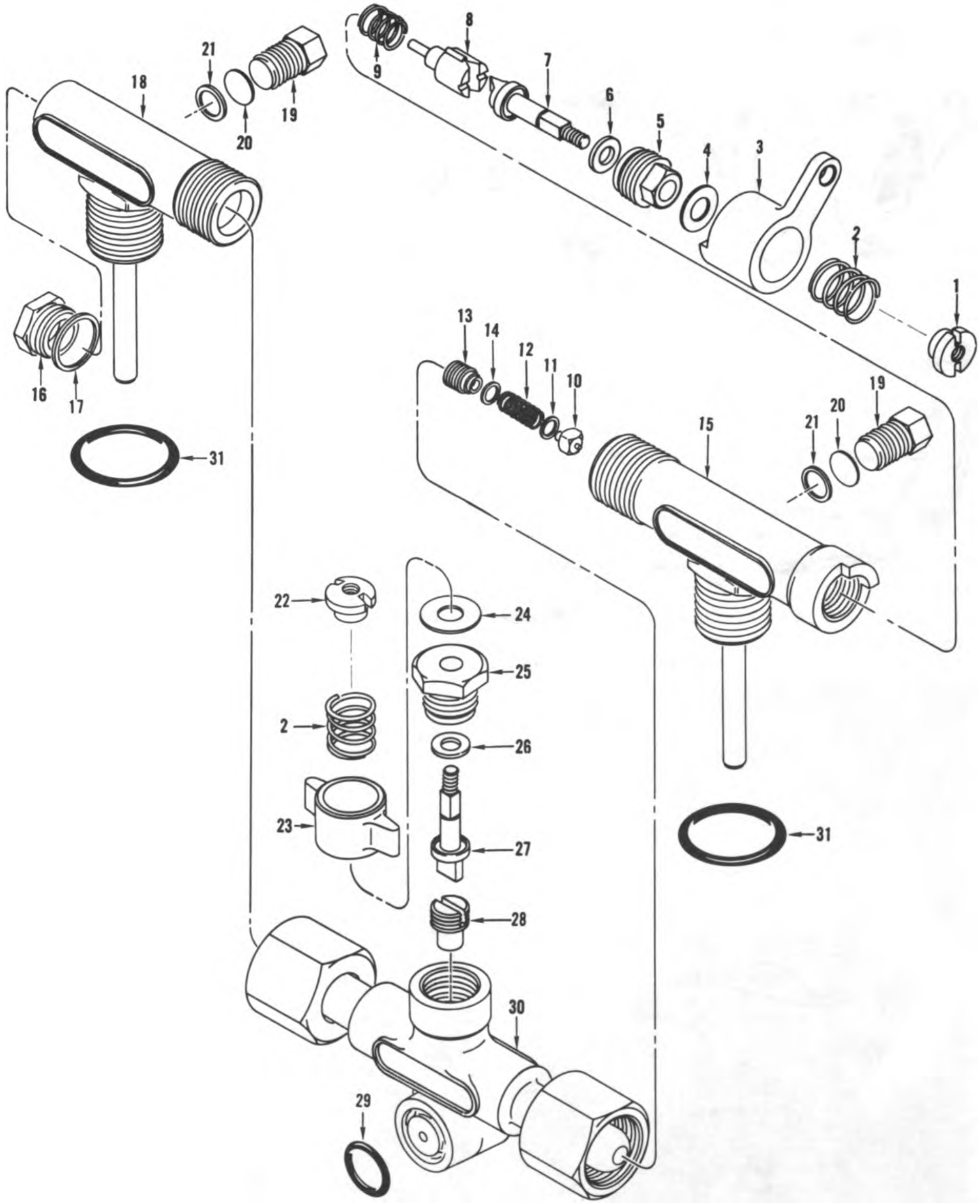


Figure D–18.—Cylinder-block manifold assembly—exploded view.

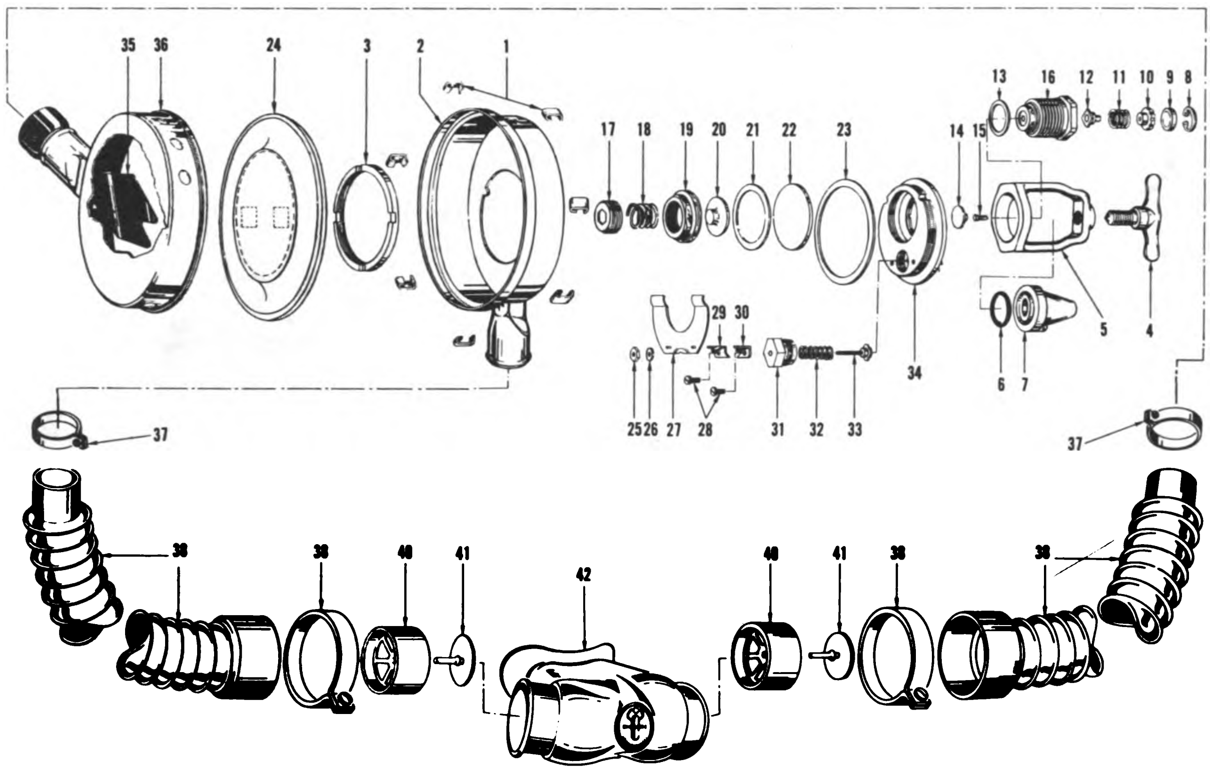


Figure D–19.—Regulator assembly—exploded view.

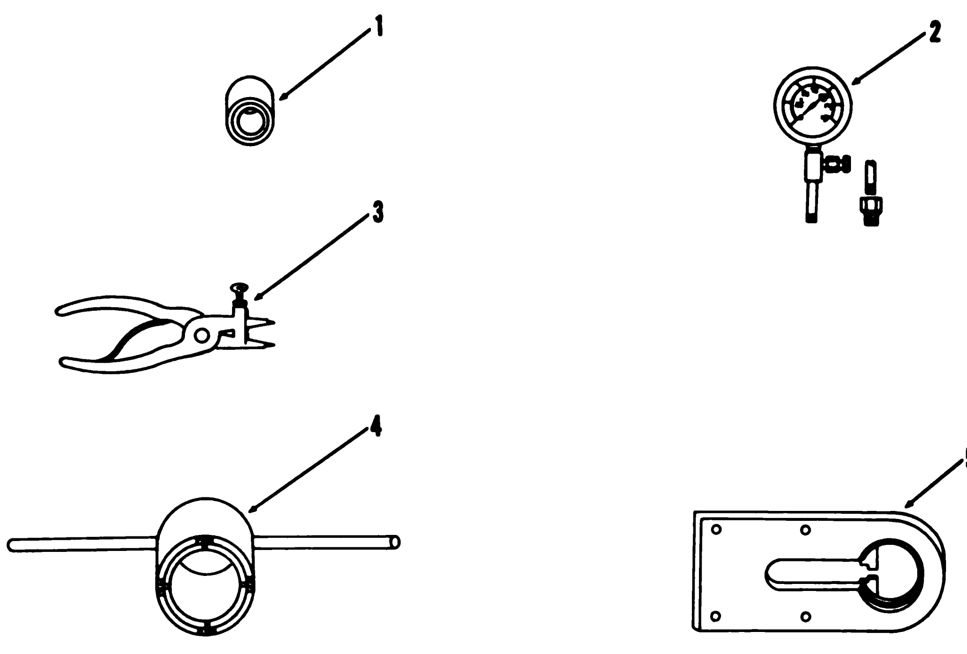


Figure D–20.—Special tools.

D–D. RECIRCULATING UNDERWATER BREATHING APPARATUS, CLOSED-CIRCUIT, OXYGEN

SECTION 1 GENERAL INFORMATION

1.1 GENERAL DESCRIPTION

The U.S. Navy oxygen scuba unit is a closed-circuit underwater breathing apparatus that consists of a mouthpiece-breathing valve assembly, breathing hoses, inhalation and exhalation breathing bags, carbon dioxide absorption canister, an oxygen supply cylinder, and a manually adjustable, gas-flow regulating assembly mounted on a nylon vest. Figures D–21 and D–22 show the oxygen breathing apparatus in position ready for use. The complete apparatus assembled for use weighs about 35 pounds out of water, and is approximately neutrally buoyant in use underwater.

Compressed oxygen is delivered from the high-pressure oxygen cylinder into the breathing system at the inspiratory breathing bag by a manually adjustable metering valve, and can also be introduced by a manual bypass valve.

Inhalation of oxygen from the breathing bag is accomplished via an inhalation hose, passing through a checkvalve and the mouthpiece assembly to the diver's lungs. Upon exhalation, exhaled gas passes through the mouthpiece assembly, its exhalation checkvalve and exhalation hose, into the exhalation breathing bag,

FIGURE D–21.—Oxygen recirculating underwater breathing apparatus—front view.

FIGURE D–22.—Oxygen recirculating underwater breathing apparatus—back view.

through a canister for absorption of carbon dioxide, and finally into the inhalation breathing bag.

1.2 GENERAL DATA, COMPONENT LIST

(*a*) *Cylinder, valve, and regulator.*—One 2,000-psi standard cylinder of 12.7-cubic-foot capacity, with a constant-reserve valve set at 500±50 psig and a regulator preset to 80 psig. Dimensions of cylinder with valve and regulator: length, 19 inches; diameter, 4⁹⁄₆₄ inches; weight, 10 pounds.

(*b*) *Backplate, cover, and canister assembly.*—The backplate, 22½ inches long by 12 inches wide, has hinges (for the shoulder pin) at its upper edge. It provides cradles for the cylinder (on the right side) and the canister (on the left side). The three-piece fiber-glass canister is 18 inches long by 4½ inches in diameter. It has two quick-connect hose fittings, a low-pressure relief valve set at 3.0±0.5 psig, and a removable cover and inside shell. The backplate cover has two ears at its lower edge and a latch at its upper edge. The cover protects the regulator and canister. It also streamlines the unit for minimum resistance, and aids in preventing entanglement.

(*c*) *Vest, breathing bags, and mouthpiece assembly.*—A vest with two detachable bags supports the backplate assembly. The vest is nylon. The breathing bags have a three-layer construction, with cotton on the exterior and interior surfaces and an airtight rubberized center. The mouthpiece assembly which contains the checkvalves is attached to the breathing bags by two breathing hoses.

(*d*) *Waist valve assembly.*—This valve is mounted on the front, lower right of the vest and incorporates the metering valve and bypass valve.

1.3 PRINCIPLES OF OPERATION

(*a*) *Application of oxygen scuba.*—Closed-circuit oxygen diving apparatus utilizing carbon dioxide absorption permits essentially complete utilization of the available gas supply at a rate independent of depth. Diving depth and duration are limited, however, by oxygen toxicity. (See secs. 1.3.11, 1.5.7 (take special note of table 1–28), 1.6.6, and app. F (A–2(c)).)

(*b*) *Oxygen flow and the rebreathing circuit.*—The flow of oxygen into the breathing circuit should be set to the rate at which the diver uses the oxygen. This flow is set by adjusting the metering valve of the waist valve assembly. If oxygen consumption is 0.9 liter per minute, the flow should be set for 0.9 liter per minute. (See par. 3.4 for further details.)

Figure D–23 shows a diagram of the rebreathing circuit. The diver holds the mouthpiece in place in his mouth and wears a faceplate covering his eyes and nose, or he may wear a suitable full face mask. Upon inhalation, the diver receives gas directly from the right-hand breathing bag through the right-hand inhalation hose and the inhalation checkvalve. On exhalation, exhaled gas (now containing carbon dioxide from the lungs) is prevented by the inhalation checkvalve from passing back into the right breathing bag. Instead, it passes from the mouthpiece assembly through the exhalation checkvalve, and through the left-hand exhalation hose to the left breathing bag. As it enters the left breathing bag, the exhaled gas displaces gas from the left breathing bag, causing flow into the carbon dioxide absorption canister, where the carbon dioxide is removed. Gas within the canister, now freed of carbon dioxide gas, is displaced into the right breathing bag, where it remains until the next inhalation. This circuit-breathing system prevents rebreathing of apparatus dead-space gas.

1.4 DETAILED DESCRIPTION

(*a*) *Vest and backplate.*—The breathing apparatus components are supported in proper position on a vest and fiber-glass backplate (with cover). In use, the vest and backplate are secured in relation to the diver by a removable shoulder pin, which joins the upper edges of the vest and backplate, and by three pairs of side straps. Figure D–24 shows the backplate assembly.

In front, the vest is divided vertically in the midline and is provided with a zipper closure, for ease of donning and removal. The breathing bags are removable from the vest and are located to the right and left of the midline closure. Below each breathing bag is a small weight pouch closed with flaps at top and bottom by

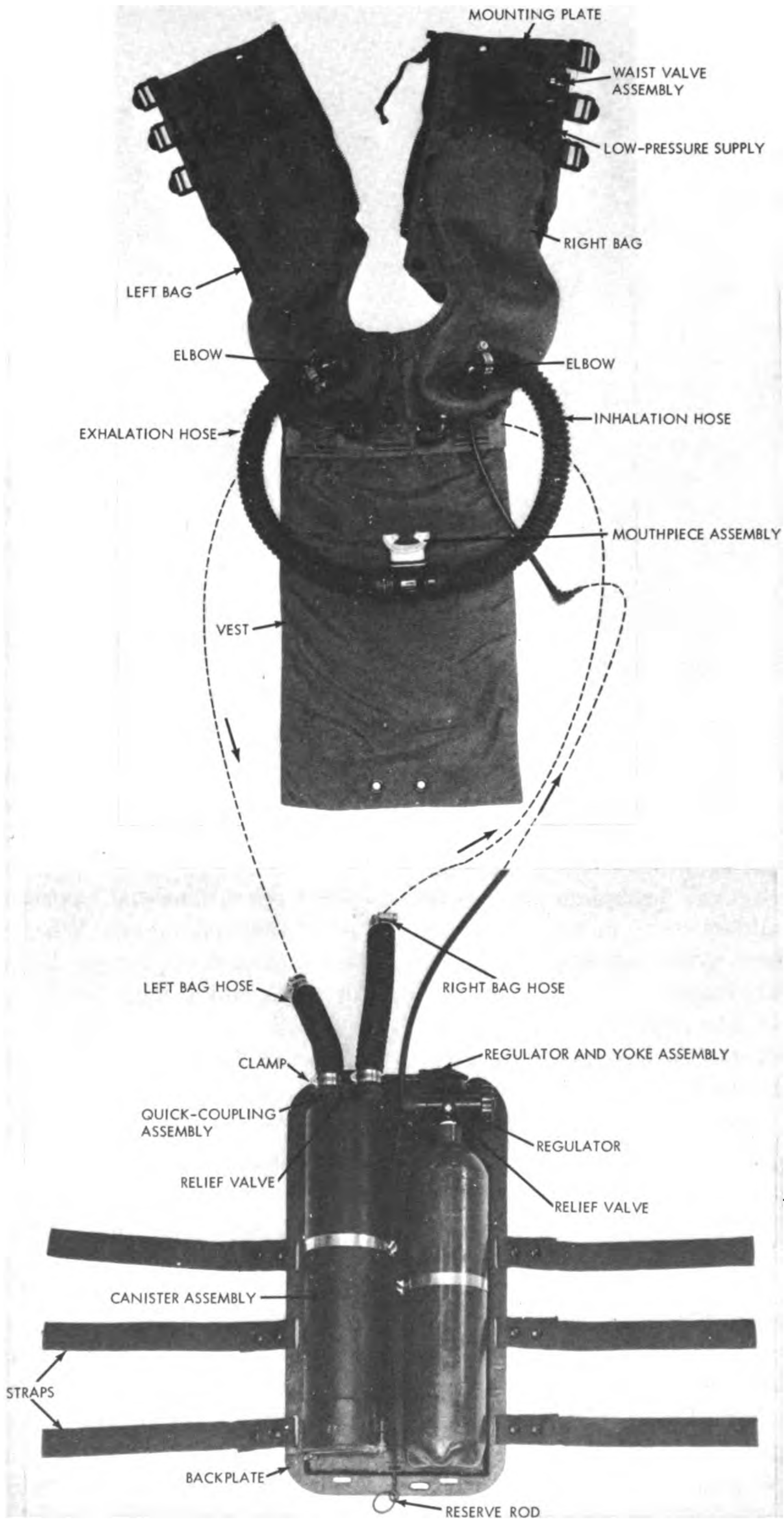


FIGURE D–23.—Diagram of breathing circuit.

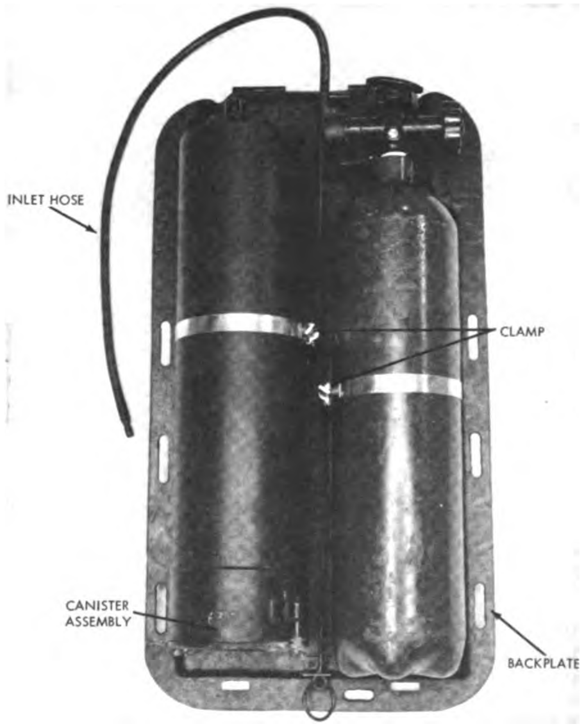


FIGURE D–24.—Backplate assembly without cover.

commonsense fasteners. Figure D–25 shows the breathing bag and vest assembly.

Buckles at the lower side corners of the vest provide means for securing and adjusting the free ends of the side straps which come from the backplate. The vest and backplate are joined back of the shoulders by a metal hinge pin which engages three nylon vest and two corresponding backplate loops.

(*b*) *Regulator.*—The regulator, shown in figure D–26, is attached to the high-pressure cylinder by a standard yoke fitting. The outlet fitting provides a connection for the low-pressure, flexible, gas-delivery tube to the rebreathing system. A relief valve is installed in the low-pressure system of the regulator.

The regulator is a compensated, nonadjustable, piston type. The body contains the filter, high- and low-pressure porting, output connection, and relief valve. The bonnet, which has a threaded connection to the body, contains the piston and spring. The regulator is preset for an 80±8 psig output. The relief valve is set to relieve at 300±50 psig.

(*c*) *Oxygen cylinder and valve.*—One cylinder is provided to contain oxygen for use in diving. The cylinder is rated for filling to 2,000 psig and has a capacity of 359.6 liters when full (12.7 cu ft). Theoretically, the full cylinder contains sufficient oxygen for almost 6 hours' use during moderate work (oxygen consumption rate=1 lpm). Practically, the useful duration of the apparatus is 120 minutes. The constant-reserve valve is set for ¼ cylinder pressure (500 ±50 psig). Pay special attention to the note in paragraph 3.4 regarding the operation of the constant-reserve valve.

In the position when worn by the diver, the cylinder is mounted vertically on the back with the neck of the cylinder up, as shown in figure D–27. In respect to the diver, the cylinder valve handle extends through the cover near the right shoulder, and the constant-reserve valve rod extends through the lower center of the cover.

(*d*) *Waist valve.*—The low-pressure outlet of the regulator is connected by a separate, flexible, pressure hose to the waist valve shown in figure D–28. Where gas enters, two flow paths are available; one to the metering valve, and the other to the bypass valve. Normally, gas entering the waist valve passes through the metering valve and out of the waist valve to the right-hand breathing bag. The metering valve handle has markings for flows of 0.5, 0.9, 2, and 3 liters per minute and has a maximum flow of 3.5 to 4 liters per minute. When the bypass valve lever is depressed, oxygen bypasses the metering valve, and a large flow goes directly to the right-hand breathing bag. The waist valve is secured to the supporting vest by four commonsense fasteners on the right-hand weight pocket.

(*e*) *Carbon dioxide absorption canister.*—The fiber-glass carbon dioxide absorption canister assembly is mounted vertically, and secured to the left side of the backplate by a clamp. The canister is cylindrical, and has an outside shell incorporating two quick-connect breathing hose fittings at its upper end and a removable cover at its lower end. Within the outside shell is a fiber-glass inside shell having a capacity of approximately 6 pounds of absorbent. At the cover or lower end of the inside shell is a removable screen, which is attached to

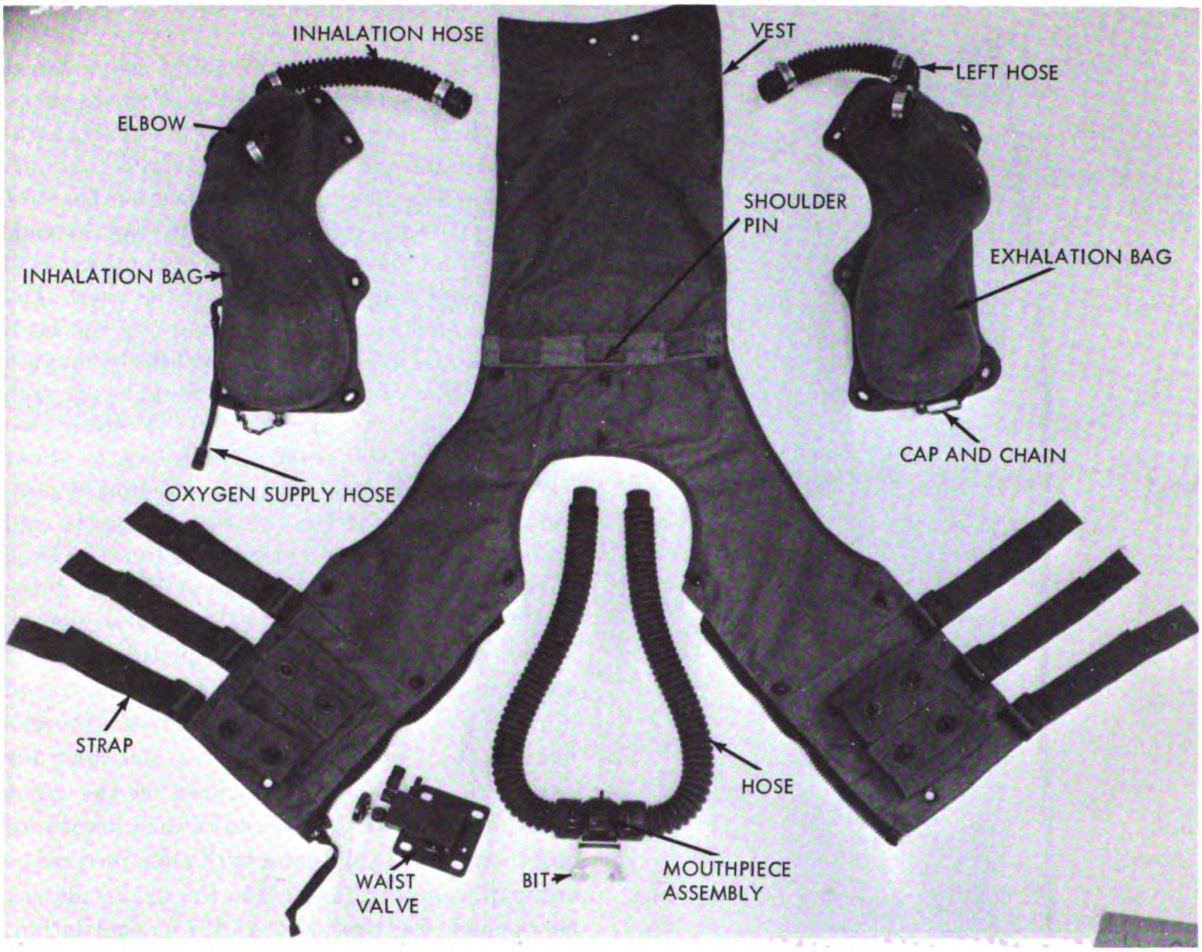


FIGURE D–25.—Breathing bags and vest assembly.

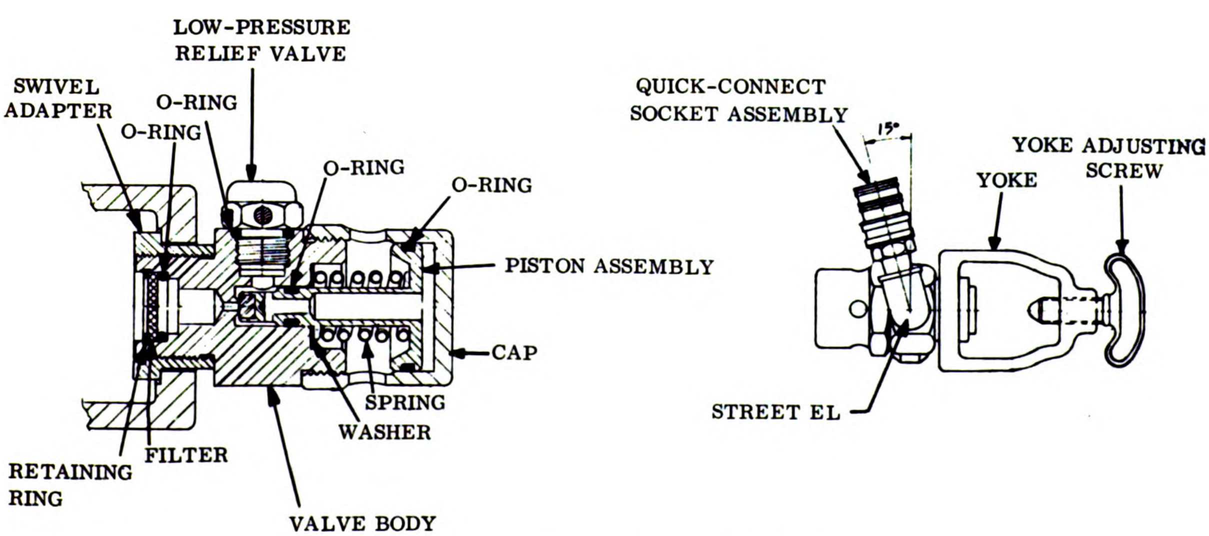


FIGURE D–26.—Regulator (sectional view).

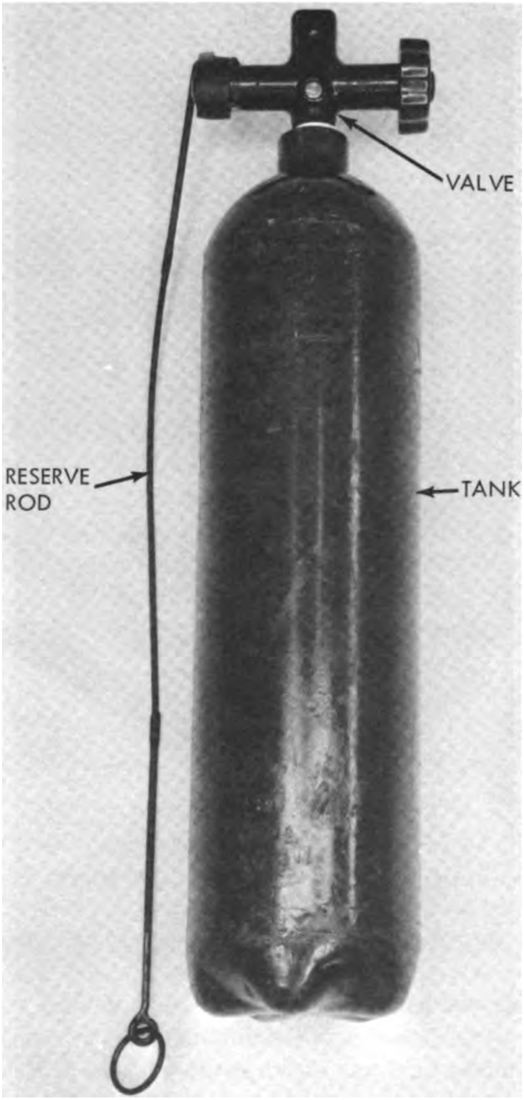


FIGURE D–27.—Cylinder assembly.

the canister cover by a spring. A similar screen is also used at the upper end of the inside shell. The inside shell is held in place 3/16 inch from the outside shell by six raised bosses on its outer surface, and is connected directly to one of the canister outlets by an O-ring seal. Thus, the gas passes between the inside and outside shells to the lower or cover end, and returns through the absorbent in the inside shell and out to the breathing bag (see fig. D–29). The canister cover equipped with an O-ring seal and a secondary flat-ring seal is held in place by two cover-clamp thumbscrews which are permanently attached to the cover. The inside shell is removable for periodic cleaning and inspection.

There is an overpressure relief valve set at 3.0 ± 0.5 psig mounted in the top of the canister.

(*f*) *Breathing bags and vest.*—The breathing bags and vest consist of right and left breathing bags, each held in place on the vest by commonsense fasteners. Each bag extends from behind the neck, over the shoulder, and down over the upper portion of the chest. The vest provides a circular opening for the head and neck, and is joined in the midline by a nylon zipper. When inflated, the volume of each breathing bag is approximately 4 liters (see fig. D–25). On the front of each bag, at about the level of the neck opening, is mounted a removable elbow for the breathing hoses to and from the mouthpiece assembly. From the back edge of the breathing bags there extends a second removable set of breathing hose elbows. These provide means for conducting exhaled gas from the left breathing bag to the carbon dioxide absorption canister, and from the canister to the right breathing bag. An inlet for oxygen is permanently mounted on the right breathing bag. At the bottom of each breathing bag there is a drain fitting with a chained plug-and-cap assembly. After use, the drains should be opened for drainage and for ventilation. This will preserve the breathing bags when the unit is stored.

(*g*) *Mouthpiece breathing valve and breathing hoses.*—Figure D–30 shows the mouthpiece breathing valve. The rubber mouthpiece bit is attached to the outer shell of a molded nylon mouthpiece body. The valve has a lever that protrudes through the cover and can be rotated to an ON position, which permits the wearer to breathe, or to an OFF position, which seals the circuit from outside air or water.

In the opening at the left end of the mouthpiece body is located an exhalation checkvalve and a molded nylon valve holder. An inhalation checkvalve and valve holder are located at the right end of the mouthpiece body.

The mouthpiece breathing valve assembly is connected by appropriate fittings to the two breathing hoses. Each of these is 19 inches long with a ⅞-inch internal diameter.

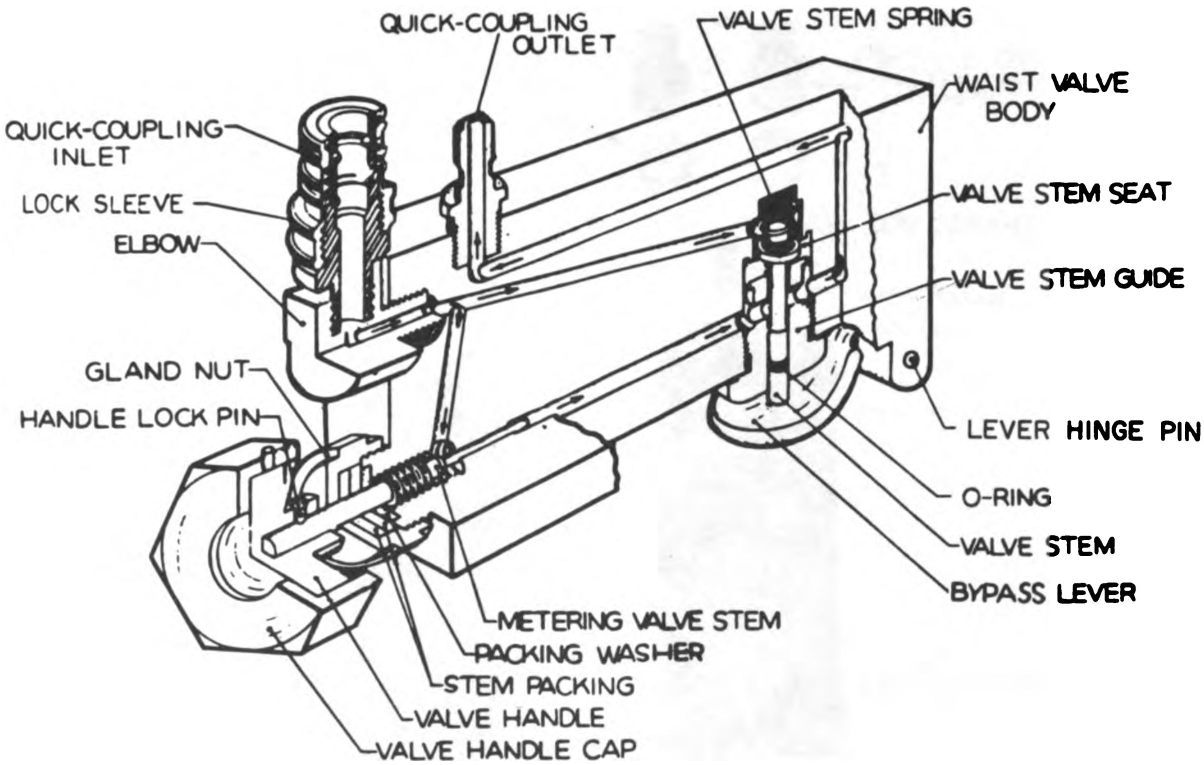


FIGURE D–28.—Waist valve (sectional view).

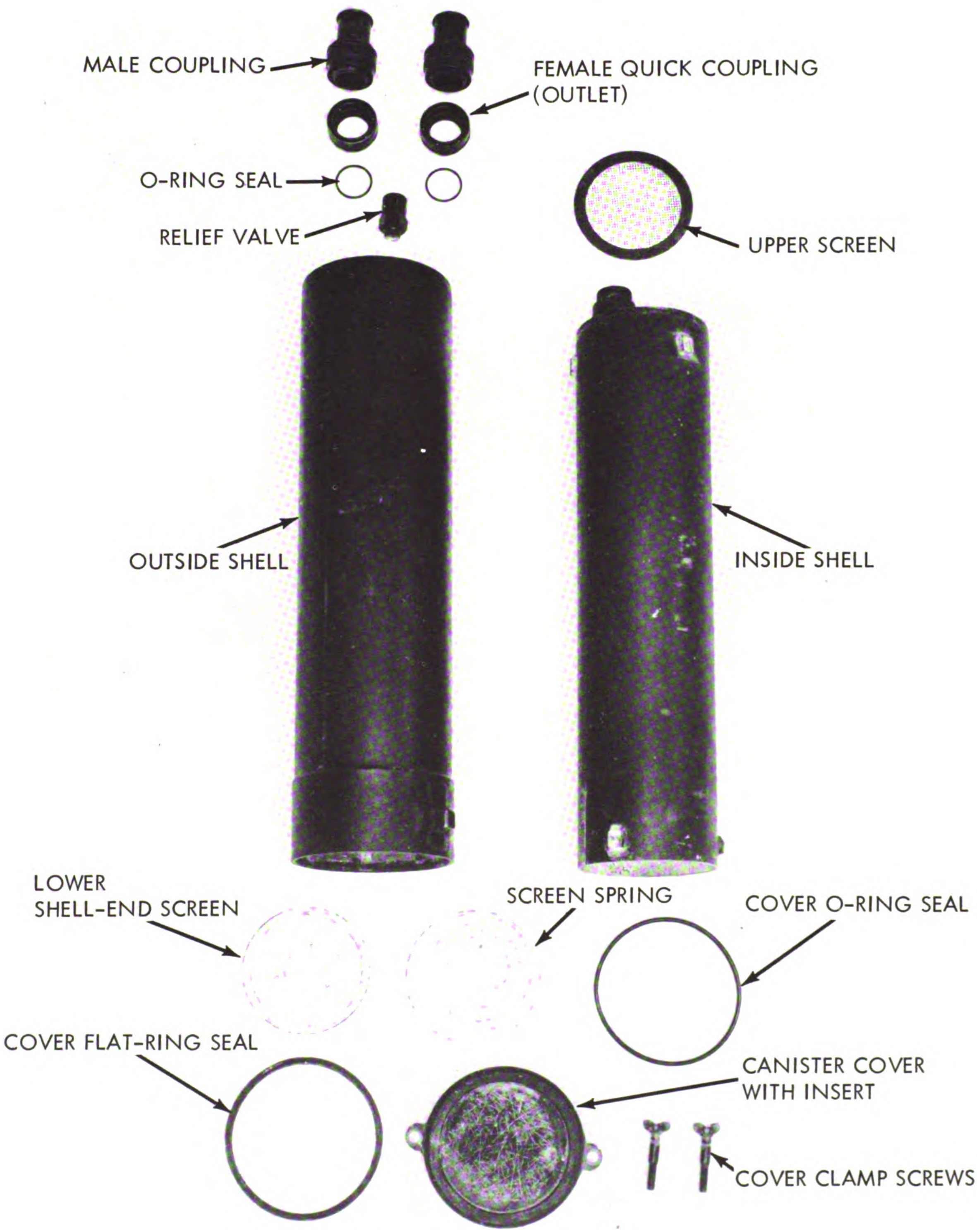


FIGURE D–29.—Canister assembly (exploded view).

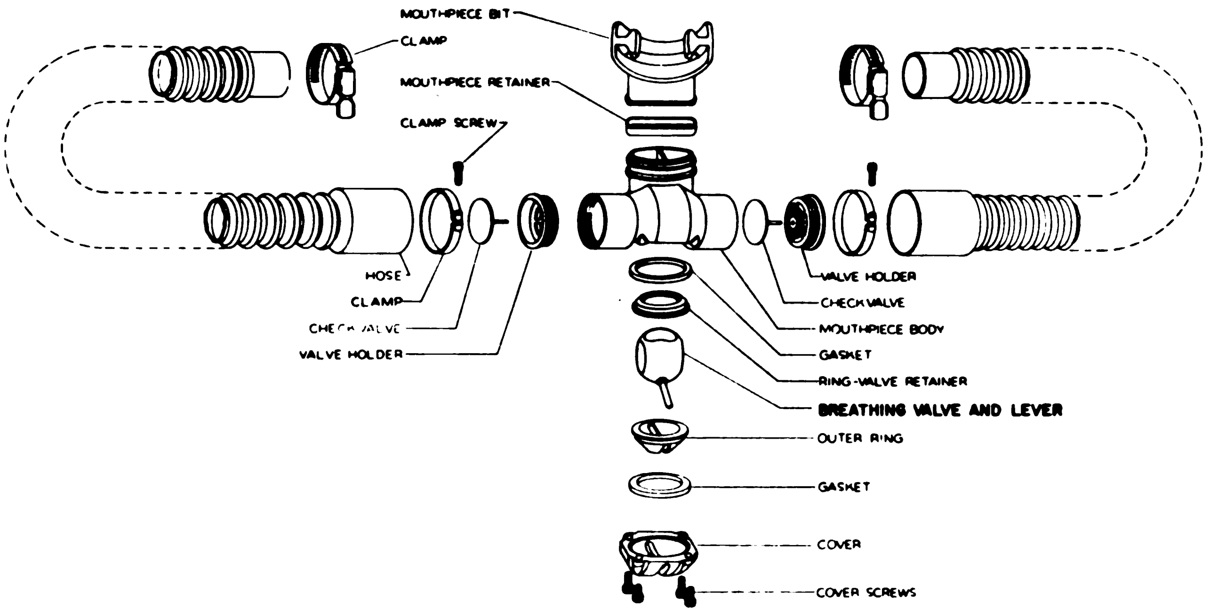


Figure D–30.—Mouthpiece and breathing valve (exploded view).

SECTION 2 INSTALLATION

2.1 HANDLING

Although the underwater rebreathing apparatus is not fragile and is constructed to resist wear or damage in normal use, it should in all phases of use, handling, and storage be treated as equipment made for the support of life under adverse conditions. Therefore, treat this gear with care.

In routine shipment, the detachable component of the apparatus should be removed, wrapped in dustless, shock-absorbent packing materials, and carefully supported with a rigid packing container. The carbon dioxide absorption canister and the gas cylinder should be emptied prior to packing for storage or shipment.

The apparatus should not be stored near fire nor at temperatures above 110° F, and should not be exposed for prolonged periods to the direct rays of the summer or tropical sun. Heating of the high-pressure cylinder can cause an increase in cylinder gas pressure, with rupture of the safety disk and violent discharge of gas.

Between periods of use, care should be taken to avoid damage to the apparatus from continuous distortion of flexible components, or pressure of heavy parts upon fabric and rubber components.

Contamination of the apparatus with oils, greases, paints, etc., should carefully be avoided. Provision should be made for drying components after use to deter rot and corrosion.

2.2 ASSEMBLY OF COMPONENTS

(*a*) *Checklist of components.*—Note the presence of each of the following:

(1) Vest and backplate.
(2) Breathing bags.
(3) Mouthpiece assembly.
(4) Canister.
(5) Cylinder with constant-reserve valve.
(6) Regulator.
(7) Waist valve.
(8) Backplate and straps.
(9) Cover.

(*b*) *Vest and breathing bag assembly.*—Tighten the four elbow connections on the breathing bags (two on each). Secure the drain plug caps. Attach the breathing bags to the vest with the commonsense fasteners.

(*c*) *Cylinder, regulator, and waist valve assembly.*—Attach the regulator to the cylinder valve and tighten its yoke securely. Attach the waist valve inlet hose to the regulator by inserting the male quick-connect fitting (elbow) firmly into its receptacle on the regulator, and securing the lock ring.

(*d*) *Final assembly.*—Note the following procedures:

(1) Place the canister assembly in the left cradle on the backplate. The two outlets are now at the upper end of the backplate. Rotate the canister so that the outlets are toward the backplate and about equidistant from it (rather than rotated away from it). Thread the retaining clamp through the cradle and fasten it securely around the canister. The thumbscrew of the retaining clamp should be positioned between the canister and the cylinder so that it does not interfere with the cover.

(2) Place the cylinder assembly in the right-hand cradle. The reserve pull rod should fall between the canister and the cylinder, and the cylinder valve should extend to the right. Now attach the retaining clamp, again positioning its thumbscrew in the central space.

(3) Attach the vest assembly to the backplate assembly by alining the three vest hinge loops with the two corresponding loops on the backplate, and by inserting and closing the shoulder pin.

(4) Attach the mouthpiece assembly to the breathing bags by the clamps provided. Be sure to attach the inhalation hose to the right bag and the exhalation hose to the left bag. In the diving (DIVE) position, the lever is pointing downward.

(5) Connect the canister to the breathing bags by inserting the male hose connections into the proper receptacles on the canister; the left bag hose to the left-hand inlet, and the right bag hose to the right-hand outlet. Do not twist or kink the hoses.

(6) Attach the backplate cover to the backplate by placing the two ears of the cover in the receiving slots at the lower edge of the backplate. Before securing the retaining latch at the top, be sure the reserve arm is in the START DIVE position, and that the reserve rod from the reserve arm extends through the slot provided for it in the bottom of the cover. Close the cover and secure the retaining latch.

(7) After weights are inserted, attach the waist valve to the right-hand weight pocket by the commonsense fasteners. The metering valve should point to the right and the bypass valve should be at the lower edge. Connect the breathing bag supply hose and waist valve inlet hose to the waist valve by placing the quick-connect fittings down over their counterparts on the waist valve. When the fitting is snapped in place, rotate the locking ring clockwise to prevent the fitting from inadvertently becoming disengaged.

(8) When the operating instructions in section 3 are followed, the unit is ready for use.

SECTION 3 OPERATING INSTRUCTIONS

3.1 PREPARATION OF APPARATUS FOR USE

(*a*) *Charging the oxygen cylinder.*—The oxygen cylinder should be filled with medically pure oxygen (FSN 9G683–290–4290) to a pressure of 2,000 psig.

(1) Remove the regulator from the cylinder valve, place the reserve arm in the RESERVE position, and open the reserve valve handwheel fully.

(2) Clear the high-pressure filling line of gas and particles by a short blast of gas from the high-pressure oxygen source.

(3) Connect the high-pressure oxygen source to the valve on the cylinder.

(4) Slowly open the valve of the high-pressure oxygen source, and fill the apparatus cylinder to the desired pressure, taking at least 5 minutes per 1,000 psig. The cylinder will become warm during filling. Allow the cylinder to cool, and finish charging if maximum pressure is desired.

NOTE

To insure maximum pressure, the cylinder should be cooled by immersing it in a bucket of water during charging.

(5) Close the cylinder valve handwheel and the valve of the high-pressure gas source. Then bleed the charging line, and detach the filled cylinder.

(6) Test the cylinder valve for complete closure.

(7) Reattach the regulator to the cylinder valve.

(*b*) *Precautions.*—Observe the following rules:

(1) Charge cylinders with the proper grade oxygen only.

(2) Do not charge above 2,000 psig.

(3) Before using the apparatus, place the mouthpiece in the mouth with the lever in the DIVE (downward) position, squeeze closed the inhalation (right-hand) hose, and try to inhale through the mouthpiece. Next squeeze closed the exhalation (left-hand) hose and attempt to exhale through the mouthpiece. If it is possible to inhale with the inhalation hose closed or exhale with the exhalation hose closed, the check valves are improperly positioned or faulty. Do not use the apparatus until this condition has been corrected.

WARNING

Avoid all contact of oil or grease with high-pressure fittings. Such material exposed to oxygen under high pressure may explode. The oxygen cylinder should be treated with care. See section 1.7, General Safety Precautions.

(*c*) *Loading carbon dioxide absorption canister.*—The carbon dioxide absorption canister must be filled with Baralyme (barium and calcium hydroxide, a commercially available product). It is carried in the Navy Stock System under FSN 6505–053 2461 (granular 7 lb).

To load the carbon dioxide absorption canister:

(1) Remove the canister from the backplate, and detach the two quick-connect fittings of the hoses from the canister.

(2) Detach the canister cover by loosening the cover-retaining thumbscrews simultaneously. Lift the cover off gently with the screen attached.

(3) Empty the canister of used absorbent.

(4) Wipe the canister free of absorbent dust.

(5) Insert the canister charge funnel in the open end of the inside shell. Fill the inside shell with screened absorbent that has been blown free of dust. To insure proper packing of absorbent granules, tap the canister with the hand as it is filled. The canister should be filled to the bottom lip of the funnel or to within about ¼ inch of the top of the inside shell.

(6) Hold the screen and cover assembly in place over the open end of the inside shell and blow sharply through the outlet quick-disconnect fitting several times to clean the canister of any remaining dust.

(7) Replace the canister cover in its indexed position, making sure that the O-ring and its seat are clean (a small amount of Dow Corning No. 4 silicone lubricant is recommended for the O-ring), and that the cover flat-ring seal seats properly on the canister rim. Secure the retaining thumbscrews firmly.

(8) Reattach the canister to the backplate in the correct position.

(*d*) *Checking apparatus for gas leakage.*—The entire apparatus, including the high-pressure and low-pressure gas delivery systems and the rebreathing system, can be tested for defective connections as follows:

(1) Close mouthpiece shutoff valve.

(2) Open the cylinder valve and metering valve, then fill the breathing bags to a firm condition by depressing the bypass valve. Close the cylinder valve to stop gas flow through the waist valve. No excess gas pressure now exists in either the high- or low-pressure gas systems.

(3) Immerse the entire apparatus in water and carefully search for sources of leakage in the rebreathing system.

(4) Carefully search for leaking gas at the delivery connections, using soap suds, Leak-Tek, or similar commercial products.

(5) When finished, relieve the pressure in the breathing system by opening the mouthpiece valve.

3.2 PREDIVE INSPECTION

When the canister and cylinder are full and the unit has been checked for leaks, a final routine predive inspection should be made before donning the apparatus.

(1) Check all fittings and screws for tightness. Pay careful attention to the five quick-connect fittings.

WARNING

Check all five quick-connect fittings for complete closure. Be sure lock rings are tight, then tug on hoses to insure that they are securely locked.

(2) Check the breathing bags for torn edges or worn spots that might rupture during use.

(3) Insure that the breathing bag drain caps are tightly in place.

(4) Make sure that the shoulder pin passes through all three loops on the vest, as well as both hinge loops on the backplate, and that it is closed.

(5) Check the breathing hoses by stretching and inspecting for pinholes and possible deterioration of the neoprene (this is indicated by numerous small cracks on the exterior surface).

(6) Check the mouthpiece valve assembly, as in paragraph 3.1(*b*)(3).

(7) Close the metering valve and slowly open the cylinder valve handwheel all the way. Insure that the reserve arm is in the START DIVE position. The apparatus is now ready to don.

3.3 DONNING THE APPARATUS

Use the apparatus only after proper charging of the cylinder and canister, a thorough check for gas leakage, and a complete predive inspection.

(1) Place the apparatus over the shoulder with the front vest zipper open. Close the front zipper, and adjust the side harness straps securely.

(2) Close the mouthpiece shutoff valve and inflate the breathing bags by depressing the bypass lever. Check the closed mouthpiece valve for tightness of seal by forcibly attempting to blow air through it.

(3) Don swim fins and mask. Insert the mouthpiece in the mouth, and open it to connect with the rebreathing system.

WARNING

It is necessary to purge the rebreathing system, and it must be done with extreme care. If excess air is not removed from the breathing bags and from the lungs before oxygen breathing starts, a considerable amount of nitrogen will remain in the respiratory system. This may be sufficient to provide a breathable volume of nitrogen after all the oxygen has been used. Because the body requirements for oxygen will not be satisfied, unconsciousness or death may occur from lack of oxygen (hypoxia). *Hypoxia gives no warning signals.* The large volume of the breathing bags (8 liters) increases the danger if the system is not purged. Thus, the technique for removing air from the bags and lungs should be followed carefully. If this is done, there is no danger.

(4) Purge the system as follows:

(*a*) Empty the breathing system. Do this by closing the metering valve, opening the mouthpiece valve, inhaling, closing the mouthpiece valve, and then exhaling to the atmosphere. Repeat this operation until the bags are sucked empty and are *completely collapsed.*

(*b*) With the bags collapsed, the mouthpiece valve in the closed position, and the cylinder valve open, add oxygen to the rebreathing system using the bypass valve until it is approximately three-quarters full.

(*c*) Now exhale, insert the mouthpiece, and open the mouthpiece valve. Purge the lungs by inhaling from the mouthpiece, closing the mouthpiece valve, removing it, and then exhaling to the atmosphere. Add oxygen as required by operating the bypass valve. Breathe down the bags three times, being careful not to allow any atmosphere to enter the breathing apparatus or lungs. If this occurs, steps (*a*) through (*c*) must be repeated.

(*d*) If the mouthpiece (or faceplate) is removed before entering the water, the breathing bags and diver's lungs must be purged again.

(*e*) Adjust the oxygen level in the bags, using the bypass valve, and set the metering valve to the appropriate setting. To start a dive, 0.9 liter is usually adequate.

3.4 DESCENT

(*a*) *Start of dive.*—When the apparatus is properly donned and functioning, obtain approval from the diving supervisor to enter the water. Set the metering valve; enter the water and make, or have a swim buddy make, a final check for leaks. Do the same for the swim buddy. Descend to the directed swim depth using the bypass valve as necessary to maintain adequate breathing gas in the breathing bags.

(*b*) *Maintaining neutral buoyancy.*—During descent, the decrease in the bag volume due to compression by water pressure may result in negative buoyancy and increasingly rapid descent. The preset flow should be supplemented on descent by intermittent use of the bypass valve to adequately maintain the volume of the bags for breathing, and for control of rate of descent. The diver must not descend more rapidly than the breathing volume can be restored. To do so will result in squeeze of the bags and lungs, as well as of structures within the faceplate.

NOTE

The cylinder constant reserve valve is set for 500±50 psig, but it starts restricting the gas flow at approximately 800 psig. The flow rate between 800 psig and 500 psig is adequate to maintain a constant bag level, but is not enough to give full flow through the bypass valve. If it is necessary to use the bypass valve and the flow appears to be inadequate, it is an indication that the cylinder pressure is somewhere between 800 and 500 psig. For full flow, the constant reserve valve rod must be pulled to place the valve in reserve condition.

3.5 DIVING LIMITS OF OXYGEN

For safe diving limits with pure oxygen, see figures 1–33 (p. 167) and D–31; also section 1.5.7.

3.6 ASCENT

WARNING

Because the apparatus has no exhaust valve, excess gas must be expelled through the mouth (or nose) during ascent to prevent lung damage and embolism.

3.7 DITCHING

Unless the mouthpiece is lost and the apparatus is accidentally flooded, there is no reason to ditch it because it will provide a certain amount of buoyancy.

OXYGEN DEPTH-TIME LIMITS

(Depth and time limits of exposure when breathing pure oxygen during working dives.)

1. NORMAL OXYGEN LIMITS

DO NOT DIVE DEEPER THAN 25 FEET

Observe these time limits:

Depths (ft)	Time (min)
10	240
15	150
20	110
25	75

2. LIMITS FOR EXCEPTIONAL OPERATIONS*

3. EMERGENCY LIMITS*

FIGURE D–31.—Oxygen depth-time limits. (*See table 1–28, p. 166.)

If the apparatus is accidentally flooded, follow this procedure:

(1) Release the six side buckles by rapidly pulling each buckle tab forward, making sure that the straps disengage with each motion.

(2) Open the vest zipper, and part the vest to either side.

(3) If possible, take a breath and swing the mouthpiece over the head.

(4) Be sure to exhale during the ascent.

SECTION 4 PREVENTIVE MAINTENANCE

4.1 ROUTINE CLEANING

(*a*) *Salt removal.*—As soon as practicable after each day's use in salt water, thoroughly rinse the outside of the apparatus with fresh water. This is best done by hosing or dipping the entire assembled apparatus into a large can of fresh water, first making sure that the mouthpiece shutoff valve and bag drains are closed and all gas delivery fittings are connected. This procedure will wash salt off the fittings.

(*b*) *Alkali removal.*—If the breathing system has been flooded during use to the extent of wetting the carbon dioxide absorbent, wash the inside of the entire respiratory system (breathing bags, canister, breathing hoses, and mouthpiece assembly) to remove alkali. Do not wash the gas delivery system if it is clean. Instead, disconnect the two hoses from the waist valve so moisture will not reach it. If possible, dry all components before reuse.

If flooding causes entrance of water and alkali into the gas delivery system, corrosion and crystallization may in time obstruct passages in the waist valve. The waist valve should be separated from the regulator and breathing bag, and flushed copiously and repeatedly with fresh water. The waist valve and connecting hoses should be dried before reassembly. The regulator can usually be cleared of dampness by discharging oil-free oxygen through it for one or two minutes at low pressure.

(*c*) *Canister cleaning.*—Periodically, the inside shell should be removed from the outside shell for cleaning and inspection. To remove the inside shell remove the cover, detach the outlet quick-connect fitting and O-ring from the canister, and slide the shell out. When it has been cleaned, reinsert the inside shell into its outside shell, making sure it is properly alined, and press firmly into place. There are two corresponding markings on the outside shell and the canister cover for easy alinement.

Remove the low-pressure relief valve from the top of the canister and inspect the sintered filter in its base; remove and clean if required.

4.2 LUBRICATION

No lubrication of metal parts of the apparatus should be necessary. If corrosion occurs on threaded areas of the fittings, clean them with a fine wire brush. Before reassembly, take care to blow corrosion dust off with oil-free compressed air or oxygen.

On the O-rings which effect seals on the fiberglass components it is advisable to use a small amount of silicon lubricant (such as Dow Corning No. 4 compound).

4.3 GENERAL INSPECTION

A general inspection should be carried out routinely in the following manner:

(1) Check all fittings and screws for tightness.

(2) Check the breathing bags and vest assembly for torn edges and punctures.

(3) Check breathing tubes by stretching and inspecting for pinholes and possible deterioration of the neoprene (as revealed by a multiplicity of small cracks on the exterior surface).

(4) Check Baralyme for excessive dampness and color change. If it is water laden, check the breathing system for leaks. Ordinarily it will be damp at the lower end and fairly dry at the top. A common cause of leakage in the canister is a faulty relief valve.

(5) Check breathing bags and mouthpiece hoses for water, and drain if necessary.

(6) Close the cylinder valve handwheel.

SECTION 5 TROUBLESHOOTING, OVERHAUL, AND REPAIR

5.1 GENERAL

Improper function of the apparatus will rarely be caused by mechanical failure of a part or wear of components, because the equipment contains few moving parts. The most common cause of malfunction will be leakage of oxygen out of the apparatus or water into it, caused by improperly maintained connections. Malfunction can be practically eliminated by careful routine inspection of the apparatus. Figures D–32, D–33, and D–34 are pertinent to this section.

5.2 LOSS OF GAS FROM APPARATUS

(*a*) *Check high-pressure system.*—Locate the source of the leak by submergence, or painting with soap solution or Leak-Tek. Repair individual leaks as follows:

(1) *Reserve-valve safety disk* (see fig. D–33).—Empty the cylinder and replace the disk.

(2) *Cylinder valve* (see fig. D–33).—Empty the cylinder, remove the valve handwheel, and tighten the gland nut. If necessary, remove the gland nut and replace the O-ring.

(3) *Reserve arm* (see fig. D–33).—Empty the cylinder, remove the reserve valve arm, and

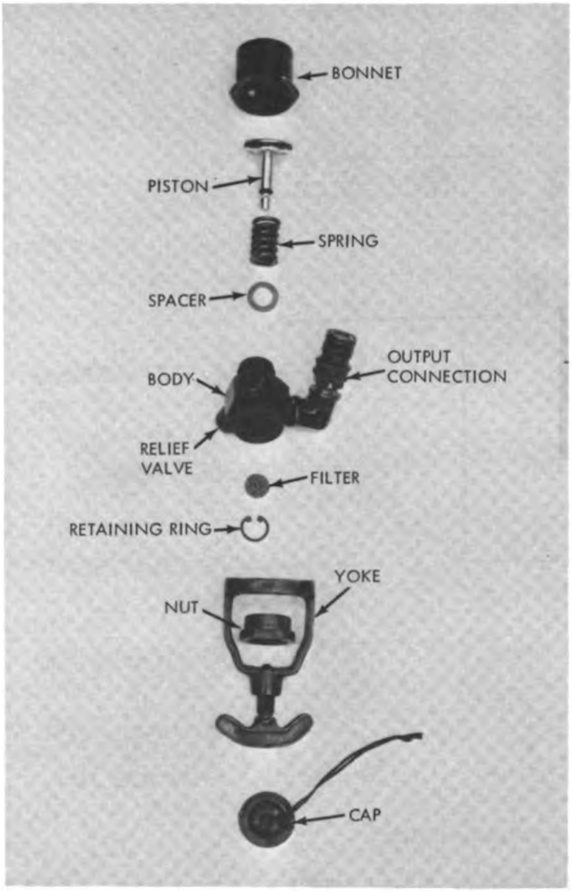


FIGURE D–32.—Regulator (exploded view).

tighten the gland nut. If necessary, remove the gland nut and replace the O-ring.

(4) *Threads between cylinder and cylinder valve* (see fig. D–33).—Remove the valve, clean the threads on both valve and cylinder, and replace. Use a small amount of oxygen service, thread-sealing compound of a type approved by the Naval Ship Engineering Center. Never use oil, grease, or paint where it can come in contact with high-pressure oxygen.

(5) *Connection between cylinder valve and regulator yoke* (see fig. D–33).—This is the most common source of high-pressure leaks and usually requires only tightening of the yoke wingnut to stop the leak. If the O-ring is damaged, replace it.

(*b*) *Check low-pressure system.*—First check the high-pressure system, as in 5.2(*a*) above. Locate the source of the low-pressure leak by submerging or painting system with soap solution.

(1) *Regulator body low-pressure fitting* (see fig. D–32).—Remove, clean the threads, and replace using a thread-sealing compound of a type approved by the Naval Ship Engineering Center as in paragraph 5.2(*a*)(4) above.

(2) *Regulator relief valve* (see fig. D–32).—Replace sealing O-ring.

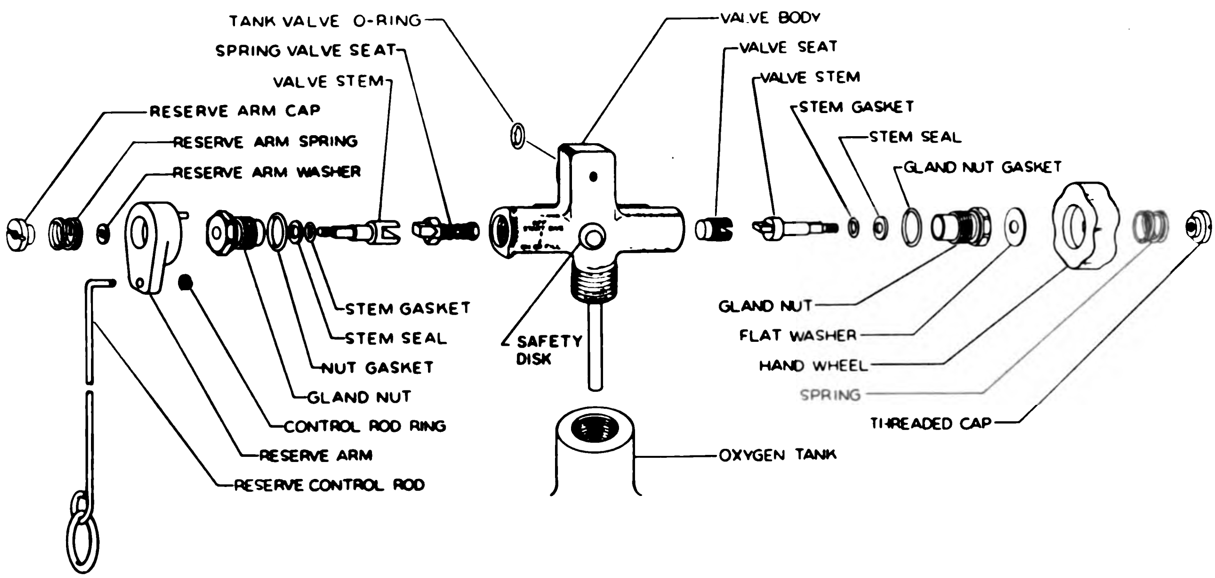


FIGURE D–33.—Cylinder and constant-reserve valve (exploded view).

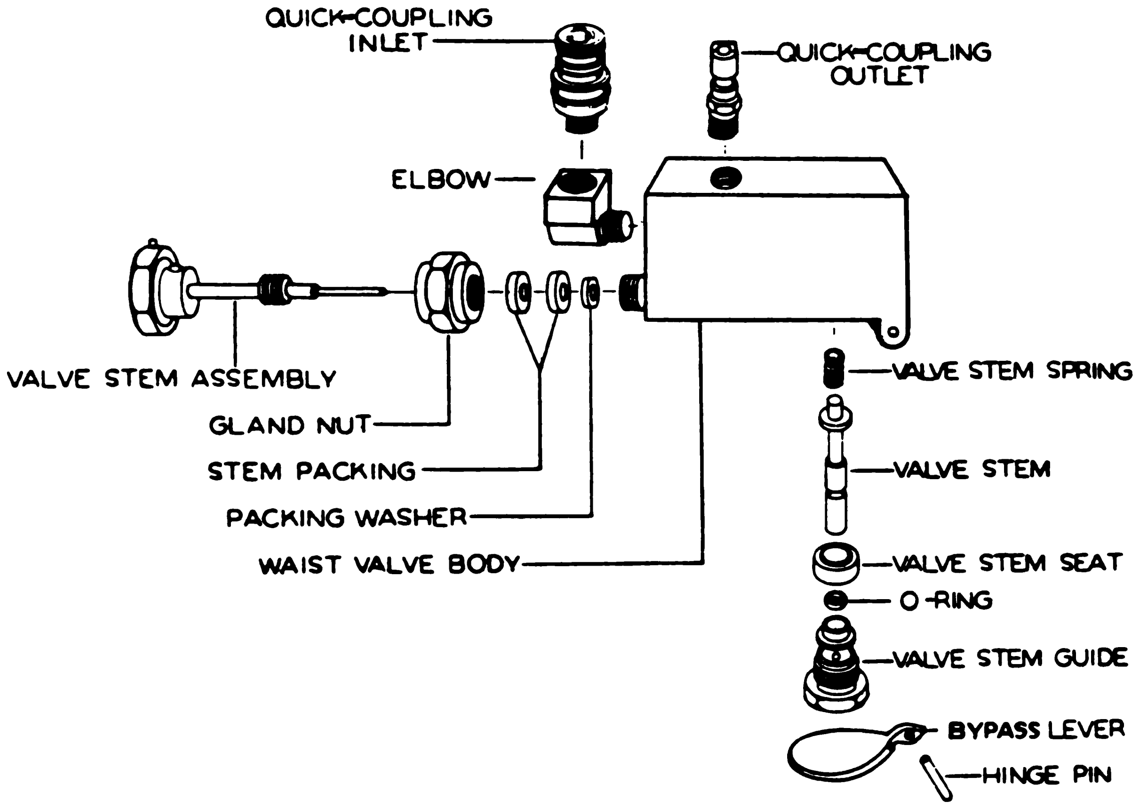


FIGURE D–34.—Waist valve (exploded view).

(3) *Regulator inlet hose* (see fig. D–32).—Replace leaking hose or damaged pressure fitting.

(4) *Waist valve* (see fig. D–34).—Remove and clean or replace leaky fittings. Replace defective quick-connect fittings. Replace the packing in the metering valve. Replace damaged O-rings.

(*c*) *Check rebreathing system.*—Close the mouthpiece shutoff valve, and inflate the breathing bags as in paragraph 3(1)(*d*). Locate the source of the leak by submerging, etc.

(1) *Canister cover.*—Correct for overfilling of canister by removing some of the absorbent. Reseat or clean the canister cover O-ring and seal if displaced or dirty. Replace canister cover if damaged. The most likely cause of leakage is a dirty canister cover O-ring.

(2) *Breathing hoses and connections.*—Tighten loose connections and replace worn hoses.

(3) *Mouthpiece shutoff valve.*—Replace gaskets or valve clamps, as needed.

5.3 ENTRANCE OF WATER INTO APPARATUS

Neither the high-pressure nor the low-pressure gas delivery systems, even if leaking gas, should allow water to enter the apparatus during use. Water leakage into the apparatus is therefore most probably due to a defect in the rebreathing system. To detect the source of water leakage, proceed as in checking for and correcting gas leakage from the breathing system (see par. 5.2(*c*)).

5.4 REGULATOR FAILURE

If the regulator malfunctions, completely disassemble it by removing the relief valve, yoke, bonnet piston, spring, snapring, and filter. Clean all parts, except the relief valve, with a cleaning solvent approved by Naval Ship Systems Command for cleaning oxygen equipment. Blow through all passages and the filter, using approved oxygen. Inspect all parts for wear and replace as required. Allow all parts to dry and reassemble, installing new O-rings if required. Apply a small amount of oxygen lubricant approved by NAVSHIPS Inst 9320.15B of 27 December 1962 to the O-rings. Reassemble the regulator to the cylinder and check the regulated output (80±8 psig).

If the relief valve fails to actuate or reseat within a range of 300±50 psig, remove from the regulator, disassemble, clean with an oxygen cleaning agent approved by Naval Ship Systems Command, and reassemble.

5.5 REPAIRS TO RUBBER AND RUBBERIZED COMPONENTS

All rubber and neoprene components, such as hoses, rubber valves, O-rings, and the like, should be replaced if found defective because there is no sure way of repairing them.

The breathing bags and nylon vest may be repaired by standard techniques employing standard materials used for repair of U.S. Navy deep-sea diving suits.

CAUTION

When repairing a breathing bag, be careful not to cement the inner surfaces together.

5.6 MAINTENANCE OF WAIST VALVE

Because the stem has a quadruple lead thread, there is only one correct starting position if the liter flow markings are to read properly. This position can only be found by trial and error. When the stem is turned all the way in, the side of the handle marked OFF should point up (see fig. D–34).

(*a*) *If the metering valve leaks.*—First, tighten the gland nut and valve stem. If leakage continues, disassemble the gland nut, stem packings, and washer, and valve stem assembly and clean all parts thoroughly. Check the threads for wear and damage. Replace the packing, and reassemble.

(*b*) *If the bypass valve leaks.*—Remove the bypass lever by unscrewing its hinge pin. Unscrew the valve stem guide, and remove the valve stem. Clean all parts thoroughly. Replace the valve stem O-ring, and reassemble.

SECTION 6 PARTS LIST

The parts in table D–7 are listed and indented by assemblies. Column 1 indicates the part number of the maintenance part. Column 2 identifies the component by its description. Column 3 shows the quantity per assembly. Column 4 shows the manufacturer's code number. Column 5 indicates the figure in which the part is illustrated.

Table D–8 is a breakdown of the special tools and equipment. Column 1 indicates the part number of the special tool or equipment. Column 2 identifies the equipment by its description. Column 3 indicates the quantity required. Column 4 shows the manufacturer's code number.

Table D–9 lists the manufacturer's name and address. The code numbers are listed in alphanumerical order and are in accordance with Cataloging Handbook H4–1. If the manufacturer did not have a code assigned, a five-letter code was assigned to the manufacturer by technical publications.

TABLE D–7.—*Parts list*

Part No.	Description	Quantity	Manufacturer	Figure
LM906E992	Underwater breathing apparatus 9–50–04	1	05454	D–23
960B416	Shoulder pin	1	05454	D–25
906E992–4	Clamp	2	05454	D–23
LM906E955	Canister and tank assembly	1	05454	D–23
906E952	Cover assembly	1	05454	D–23
906E952–1	Fiber-glass cover	1	05454	D–23
906E928–2	Cover hinge hook	2	05454	
LM960B477	Cover latch assembly	1	05454	

TABLE D–7.—*Parts list*—Continued

Part No.	Description	Quantity	Manu-facturer	Figure
	Underwater breathing apparatus 9–50–04—Con.			
MS20615–4CU6	Rivet	6		
MS15795–504	Washer	4		
71–1–520–38	Insert	1	24248	
GS–10SS	Clamp	4	76599	D–23
906E955–13	Hose, left bag	1	05454	D–23
906E955–14	Hose, right bag	1	05454	D–23
QS–200M64	Clamp	2	AAAAA	D–23
LM934D835	Canister assembly	1	05454	D–29
LM953C580	Quick-coupling assembly	2	05454	D–29
B–1145–C	Plug	1	81895	D–29
B–1150–C	Socket	1	81895	D–29
MS29513–214	O-ring	1	81895	D–29
MS29513–22	O-ring	1	02697	D–29
991C556	Relief valve	1	05454	D–29
LM953C537	Canister cover assembly	1	05454	D–29
953C537–8	Brass wire	4	05454	D–29
LM953C546	Screen assembly	1	05454	D–29
953C554	Screen spring	1	05454	D–29
MS29513–241	O-ring	1	02697	D–29
953C723	Flat-ring seal	1	05454	D–29
5100–25	Retaining ring	2	79136	D–29
960B357	Cover clamp screw	2	05454	D–29
LM953C544	Canister cover subassembly	1	05454	D–29
LM953C546	Screen assembly	1	05454	D–29
LM934D800	Inside shell assembly	1	05454	D–29
LM934D807	Outside shell assembly	1	05454	D–29
960B459	Ring spring	1	05454	D–27
LM960B435	Reserve control rod	1	05454	D–27
960B436	Hose assembly, regulator to valve	1	05454	D–24
189	Male, quick-coupling	2	73992	
622	Ferrule brass	2	53477	
C403	Hose to regulator neoprene	1	30327	
4267–051–1	Regulator and yoke assembly (05454 dwg. 991C880).	1	53655	D–32
57360–00	Socket assembly	1	53655	D–32
COML	Street el (Imperial 116B)	1		D–32
4267–052	Screw, yoke-adjusting	1	53655	D–32
4267–056	Yoke	1	53655	D–32
4267–055	Cap	1	53655	D–32
4267–053	Relief valve, low-pressure	1	53655	D–32
COML	O-ring	2		D–32
4267–051–010	Plug	1	53655	D–32
3348–12	Piston assembly	1	53655	D–32
COML	O-ring, size 019	1		D–32
3594–3	Spring	1	53655	D–32
6526	Washer	AR	53655	D–32
COML	O-ring, size 007	1		D–32
4267–057	Swivel adapter	1	53655	D–32
N5000–50W	Retaining ring	1	79136	D–32
1665–14	Filter	1	53655	D–32
COML	O-ring, size 012	1		D–32
4267–050–3	Body, valve	1	53655	D–32
960B458	Straps, backplate	6	05454	D–23
LM953C574	Valve assembly, tank	1	05454	D–33

TABLE D–7.—*Parts list*—Continued

Part No.	Description	Quantity	Manufacturer	Figure
	Underwater breathing apparatus 9–50–04—Con.			
SJ	Valve, reserve	1	18801	D–33
MS28775–112	O-ring	1		D–33
LM953C575	Reserve arm assembly	1	05454	D–33
953C575–2	Pin	1	05454	D–34
953C575–1	Reserve arm	1	05454	D–33
SIZE D	Oxygen tank	1	33525	D–33
922E547	Backplate assembly	1	05454	D–24
LM906E960	Left bag assembly	1	05454	D–25
LM906E961	Right bag assembly	1	05454	D–25
LM960B353	Water drain cap assembly	1	05454	D–25
960B351	Rivet	1	05454	
960B355	Cap	1	05454	
949A401	Water drain cap seal	1	05454	
Size 2–0	Brass safety chain	AR	AAAAB	
LM960B360	Elbow assembly	2	05454	D–25
LM960B356	Assembly, fixed nut	1	05454	
960B376	Fixed nut	1	05454	
960B350	Handle, fixed nut	1	05454	
960B358	Loose washer	1	05454	
960B352	Loose nut	1	05454	
960B377	Elbow connection	1	05454	
906E960–3	Chain link, L.H	1	05454	
906E961–3	Chain link, R.H	1	05454	
906E951	Left bag subassembly	1	05454	D–25
906E959	Right gas bag	1	05454	D–25
LM953C464	Water drain assembly	1	05454	
953C459	Water drain	1	05454	
LM934D805	Waist valve assembly	1	05454	D–28
180–S–9	Female quick-coupling	1	73992	D–28
18S	Male quick-coupling	1	73992	D–28
331C201B1032C06	Screw	2		
MS35338–100	Washer	2		
MS15795–909	Washer	2		
953C527	Mounting plate	1	05454	D–23
331C251A0440D03	Lock pin, valve handle	1	05454	D–28
LM960B438	Valve handle assembly	1	05454	D–28
960B428	Valve handle	1	05454	D–28
960B430	Cap	1	05454	D–28
960B431–1	Pin, indicating 500 cc	1	05454	D–28
960B431–2	Pin, indicating 900 cc	1	05454	D–28
960B429	Gland nut	1	05454	D–28
960B434	Stem packing	2	05454	D–28
960B433	Packing washer	1	05454	D–28
960B432	Meter valve stem	1	05454	D–28
W3400X2	Street elbow	1	79470	D–28
MS35214–29	Screw, valve hinge pin	1	81349	D–28
1755–7	Flood lever	1	53477	D–28
1755W–9	Valve stem guide	1	53477	D–28
1755–4	Valve stem seat	1	53477	D–28
1755W–25	Valve stem	1	53477	D–28
934D805–10	O-ring	1	05454	D–28
1755–6	Valve stem spring	1	53477	D–28
LM934D799	Body assembly	1	05454	D–28
125002	Lee plug	1	92555	D–28
934D799–1	Body	4	05454	D–28

TABLE D-7.—*Parts list*—Continued

Part No.	Description	Quantity	Manu-facturer	Figure
	Underwater breathing apparatus 9-50-04—Con.			
LM960B426	Hose assembly, valve to vest	1	05454	D-23
180-S-9	Female quick-coupling	1	73992	
1105	Hose end	1	53477	
769	Ferrule	1	30327	
C404	Hose	1	30327	
LM953C478	Mouthpiece assembly	1	05454	D-30
1123-10	Clamp	2	94120	D-30
LM953C465	Hose	2	05454	D-30
960B366	Mouthpiece retainer	1	05454	D-30
953C478-16	Brass wire	1	05454	D-30
953C467	Bit	1	05454	D-30
953C463	Valve holder	2	05454	D-30
953C482	Check valve	2	05454	D-30
AN515B6-10	Screw	4		D-30
953C458	Cover	1	05454	D-30
960B364	Gasket	1	05454	D-30
960B365	Gasket	1	05454	D-30
953C462	Retainer, ring valve	1	05454	D-30
953C466	Outer ring, mouthpiece	1	05454	D-30
953C461	Valve, mouthpiece	1	05454	D-30
953C460	Lever	1	05454	D-30
934D722	Body	1	05454	D-30
LM906E915	Vest assembly	1	05454	D-23

TABLE D-8.—*Special tools and equipment*

Part No.	Description	Quantity	Manu-facturer
949A471	Regulator key (¼ in. allen wrench)	1	05454
953C665	Bonnet wrench	1	05454
953C666	Charging line assembly	1	05454
953C666-7	Oxygen swivel nut	1	05454
953C666-6	Hose (6 feet)	1	05454
953C666-4	Gage 4M PS1	1	05454
960B509	T-handle assembly	1	05454
960B509-1	T-handle	1	05454
960B509-2	Clamp pin	1	05454
953C666-2	Filter	1	05454
953C678	Yoke assembly	1	05454
960B512	Gage T-connection	1	05454
953C677	Elbow spanner wrench	1	05454

TABLE D–9.—*List of manufacturers*

Code No.	Name and address	Code No.	Name and Address
AAAAA	Aero Seal Corp. Baltimore, Md.	76599	Murray Corp., 600 East Joppa Rd., Towson, Md.
AAAAB	Montgomery Ward & Co., Baltimore, Md.	79136	Waldes Kohinor, Inc., 47-16 Austel Pl., Long Island City, N.Y.
02697	Parker Seal Co., Cleveland, Ohio.	79470	Weatherhead Co., Cleveland, Ohio.
18801	Sportsway, Inc., Paramount, Calif.	81349	Joint Army-Navy specifications promulgated by Standardization Division Directorate of Logistic Services, DSA.
24248	South Chester Corp., Lester, Pa.	81895	Breco Division, Perfecting Service Co., Charlotte, N.C.
30327	Imperial-Eastman Corp., 6300 West Howard St., Chicago, Ill.	92555	Lee Co., Westbrook, Conn.
33525	Kidde, Walter & Co., Inc. Belleville, N.J.	94120	U.S. Diver Co., Los Angeles, Calif.
53477	Schraders & Sons, division of Scovill Mfg. Co., Brooklyn, N.Y.		
53655	Scott Aviation, Lancaster, N.Y.		
73992	Hansen Mfg. Co., 4033 West 150th St., Cleveland, Ohio.		

D–E. MK VI UNDERWATER BREATHING APPARATUS

SECTION 1 GENERAL DESCRIPTION

1.1 The Mk VI underwater breathing apparatus is a semi-closed-circuit, continuously flowing, recirculating, mixed-gas, underwater breathing system (see fig. D–35).

1.2 The Mk VI underwater breathing apparatus, hereafter referred to as the breathing apparatus, consists of two high-pressure, spun-aluminum cylinders (1), and a high-pressure

1. Cylinder
2. Manifold valve assembly
3. Regulator assembly
4. Control block assembly
5. Canister assembly
6. Breathing bag and vest assembly
7. Exhaust valve
8. Mouthpiece T-tube assembly
9. Back plate

FIGURE D–35.—Mk VI underwater breathing apparatus.

brass manifold valve assembly (2); a single-stage, aneroid-controlled, constant-mass, flow-regulator assembly (3); a control block assembly (4); a canister assembly (5); a detachable breathing bag and vest assembly (6) with adjustable body straps; an exhaust valve (7) mounted in the exhalation breathing bag; a mouthpiece T-tube assembly (8); and a backplate (9).

SECTION 2 PRINCIPLES OF OPERATION

2.1 GENERAL APPLICATION OF MIXED-GAS SCUBA

2.2 Semi-closed-circuit, mixed-gas, underwater breathing apparatus represents a practical compromise between the need for increased depth and duration of dive, the size and complexity of breathing apparatus, and the requirements for safety of personnel.

2.3 While closed-circuit diving apparatus using pure oxygen and carbon dioxide absorption permits essentially complete utilization of the available gas supply at a rate independent of depth, diving depth and duration are limited by oxygen toxicity. With open-circuit diving apparatus using air, diving depth and duration are sharply restricted by the low efficiency of gas utilization resulting from complete discharge of each exhalation. In terms of oxygen, the efficiency of gas utilization with open-circuit apparatus is approximately 5 percent near the surface and decreases with increasing depth. For this reason, the use of nitrogen-oxygen or helium-oxygen mixtures other than air in open-circuit systems provides only small gains in diving depth and duration over the use of air in the same apparatus.

2.4 Semi-closed-circuit, mixed-gas apparatus employs partial rebreathing and carbon dioxide absorption to improve the efficiency of gas supply utilization. A continuous, steady flow of new gas into the rebreathing system provides a continuous purge to prevent excessive deviations of bag gas concentration from the desired level. Therefore, inflow of mixed gas into the breathing system must always be in sufficient excess over the rate of utilization of the oxygen it contains to keep oxygen concentration from falling below the normal level of approximately 21 percent.

2.5 In mixed gas, the supply gas mixture is selected on the basis of the dive, and the gas inflow depends on the type and degree of activity (work) performed during the dive. By employing a constant-mass flow of gas, the useful duration of gas supply is independent of diving depth. While a considerable amount of gas is discharged from the breathing apparatus, the efficiency of gas utilization with constant-mass inflow may be as much as 10 times that of open-circuit apparatus at 100 feet. At intermediate depths, the problem of decompression is diminished by using a higher oxygen percentage to dilute the inert gas (nitrogen or helium) used. When nitrogen is used, this dilution by oxygen also diminshes the problem of nitrogen narcosis to some extent. The ratio of oxygen to inert gas is selected for various depths to provide the greatest possible dilution of inert gas by oxygen without introducing oxygen toxicity as a limiting factor. With extreme depths, avoidance of oxygen toxicity requires that the dilution of inert gas by oxygen must be reduced to levels approaching the concentration of oxygen in air. Thus, the advantages of semiclosed, mixed-gas breathing apparatus in protecting against decompression sickness are greatest at shallow diving depths. These advantages become progressively less as diving depth increases and are lost entirely at a depth of approximately 300 feet. However, at all practical depths the use of constant-mass gas inflow provides greater duration of the existing gas supply. Thus the combination of gas flow and gas mixture is chosen to provide the maximum compromise in protection against decompression sickness, hypoxia, and oxygen toxicity. At the same time the combination requires the lowest rate of gas utilization to increase the time available to perform useful work for extended periods at diving depth. The longer duration of gas supply can also provide for necessary periods of stage decompression after completion of work at diving depth.

2.6 GAS COMPOSITION AND FLOW

2.7 Principles underlying selection of gas mixtures and rates of gas inflow for various diving depths include decompression sickness after exposure to increased pressure as a result of intake of an inert gas, such as nitrogen, by the body tissues, followed by decompression at a rate too fast to allow the excess inert gas to be removed from the body by the processes of circulation and respiration. In mixed-gas diving it is therefore desirable to use the highest oxygen concentration that will not introduce oxygen toxicity as a hazard.

2.8 Because an inert gas is present in the breathing mixture, it is essential that the inflow of the oxygen-containing mixture be adequate to meet metabolic needs for oxygen. If inflow is too low for the diver's activity, metabolic utilization of oxygen will reduce oxygen to levels that will result in unconsciousness from hypoxia. This is the most serious hazard of oxygen and inert gas diving. Bag levels of oxygen and inert gas can, however, be predicted if the cylinder gas composition and the rate of gas inflow are known.

2.9 THE REBREATHING CIRCUIT (see fig. D–36)

2.10 The diver holds mouthpiece (1) in place in his mouth and wears a face mask covering his eyes and nose. Upon inhalation, the diver receives gas directly from the inhalation breathing bag (2) through inhalation valve and inhalation hose (3) connecting the right side of the mouthpiece to the inhalation breathing bag. Upon exhalation, the exhaled gas (now containing carbon dioxide from the lungs) is prevented from passing back into the inhalation breathing bag by the one-way inhalation valve. Instead it passes through the one-way exhalation valve and exhalation hose (4) connecting the left side of the mouthpiece to exhalation breathing bag (5). Upon entrance to the exhalation breathing bag, the exhaled gas volume displaces gas from the exhalation breathing bag, causing it to move down through the outer shell (6) of canister assembly (7). The exhaled gas is then filtered through the Baralyme pellets contained in the inner shell (8) of the canister assembly where the carbon dioxide gas is removed. The purified gas, now free of carbon dioxide gas, is mixed with a predetermined amount of gas from cylinders (9) at the top of the canister assembly, and is displaced into the inhalation breathing bag where it remains until the next inhalation. This predetermined supply of gas from the cylinders is supplied to the top of the canister assembly via safety elbow assembly (10) and plain elbow assembly (11), manifold valve assembly (12), regulator assembly (13), control block assembly (14), control block to canister hose (15), and air inlet block (16).

2.11 This circuit-breathing system minimizes rebreathing of apparatus dead-space gas. Because of the excess of gas inflow over utilization, a relatively constant volume of gas is discharged from the rebreathing system through the exhaust valve assembly (23). Discharge of excess gas occurs at the end of each exhalation as the breathing bag (5) is filled by the exhaled gas. Failure to discharge excess gas serves as a warning of decreased inflow of gas and should be constantly watched for as a danger signal.

2.12 BAG OXYGEN CONCENTRATION

2.13 *Lower limits of bag oxygen concentration.*—The lowest permissible level of bag oxygen concentration in mixed-gas scuba diving is 21 percent oxygen. In diving or underwater swimming, the highest sustainable rate of oxygen consumption is approximately 3.0 liters per minute. Therefore, for any gas mixture the flow which results in a 21-percent oxygen level in the breathing bag at an oxygen consumption rate of 3.0 liters per minute establishes the minimal inflow permissible for the apparatus. Gas inflow for various cylinder oxygen percentages is shown in table D–10. See part 1 for equivalent air depth and decompression tables.

2.14 The determination of the maximum diving depths for various gas mixtures and gas inflows is based on the avoidance of oxygen toxicity. In practice the maximum depth that the highest percentage oxygen mixture can be breathed is the depth at which the partial pressure of oxygen equals 52.8 feet absolute. For safety reasons the supply percent of oxygen is considered the highest possible to be breathed because the bag percent will always be lower

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TABLE D-10.—*Mixed-gas flow rate table*

Inert gas	Oxygen, percent	Type of exercise	Actual flow,[1] liters per minute	Measured flow,[2] liters per minute	Maximum depth,[3] feet
Nitrogen	60	Swimming	3	3	
	40	Swimming	12	12	
	32. 5	Swimming	21	21	180
Helium	40	Swimming	11	8	140
	32	Swimming	18. 5	12. 5	180

[1] Actual flow is the precise flow as measured by an accurate instrument. The Mk VI test kit is an air-calibrated instrument which gives approximate actual flow for nitrogen and air calibrations.

[2] Measured flow is that which is found on an air-calibrated flowmeter such as that of the Mk VI and reads low for helium-oxygen mixtures. Therefore, the measured flow rates are to be used with this equipment unless other flow meters are used.

[3] The maximum depth is from part 1 and is that depth noted for operational limits which does not indicate the exceptional exposure limits.

than that of the supply. For the maximum depths, gas mixtures, and gas flows, see part 1. Maximum oxygen supply percentage or maximum depth on a given supply oxygen level can be determined by solving the following appropriate formula:

(*a*) Maximum oxygen percentage:

$$=\frac{52.8\times 100}{\text{Depth of dive in feet}}$$

(*b*) Maximum depth of dive on available mixture:

$$=\frac{52.8}{\text{Percent oxygen in available mixture}}-33$$

2.15 The depth-compensated gas-pressure regulator and the gas-flow needle-valve orifice provide the means of holding the mass flow of gas nearly constant in spite of changes in diving depth.

2.16 PREDICTION OF BREATHING BAG GAS COMPOSITION

2.17 The oxygen and nitrogen, or oxygen and helium concentrations in the rebreathing bag will not be identical to the gas entering the bag from the compressed-gas cylinders. The difference results from use of oxygen by the diver during partial rebreathing. For any rate of work or oxygen utilization by the diver, the bag oxygen percentage can be accurately predicted if the cylinder gas composition and the rate of gas inflow are known. For example, assume—

Cylinder gas	=60 percent oxygen and 40 percent nitrogen
Constant gas inflow rate	=8 liters/min (STPD)
Diver oxygen consumption at rest	=0.5 liter O_2/minute
Diver oxygen consumption during heavy underwater work	=3.0 liters O_2/minute

Under these conditions, the breathing bag (inspired) oxygen and nitrogen concentrations during rest and during heavy work can be determined by using the formulas expressed below:

(*a*) Percent oxygen in bag:

$$=\frac{100(O_2\text{ inflow}-O_2\text{ consumption})}{\text{Total gas inflow}-O_2\text{ consumption}}$$

(*b*) Percent oxygen in bag:

$$=\frac{100(\text{percent }O_2\text{ in total gas})\,(\text{cylinder inflow})-O_2\text{ consumption}}{\text{Total gas inflow}-O_2\text{ consumption}}$$

Using formula (*b*) it is possible to calculate bag oxygen concentration by substituting the values for gas inflow and composition, and for the diver's oxygen consumption rate in the appropriate places. Examples:

(*a*) Resting percent oxygen in bag:

$$=\frac{100\ (60\ \text{percent}\times 8\ \text{liters/min})-0.5\ \text{liter/min}}{8\ \text{liters/min}-0.5}$$

$$=\frac{100\ (4.8-0.5)}{7.5}$$

$$=\frac{100\ (4.3)}{7.5}=57.3\ \text{percent}\ O_2\ \text{in bag at rest}$$

(*b*) Working percent oxygen in bag:

$$=\frac{100\ (60\ \text{percent}\times 8\ \text{liters/min})-3.0\ \text{liters/min}}{8\ \text{liters/min}-3}$$

$$=\frac{100\ (4.8-3)}{5}$$

$$=\frac{100\ (1.8)}{5}=36\ \text{percent}\ O_2\ \text{in bag at work}$$

From the examples it can be seen that during a dive, changes in the diver's rate of oxygen consumption between 0.5 and 3.0 liters per minute will cause fluctuation in bag gas composition from a 57.3-percent-O_2–42.7-percent-N_2 mixture at rest, to a 36-percent-O_2–64-percent-N_2 mixture at work. During these fluctuations, the gas entering the bag from the cylinder remains fixed at 8 liters per minute at a 60-percent-O_2–40-percent-N_2 mixture.

SECTION 3 DETAILED DESCRIPTION

3.1 The breathing apparatus components are supported in proper position on breathing bag and vest assembly (17, see fig. D–36) and the backplate (18). In use, the backplate is secured to the breathing bag and vest assembly with toggle pin assembly (19) at the upper edges of the vest and backplate, and by three pairs of side straps (20). The gas cylinders are secured to the backplate with two cylinder straps (21) and a cylinder spreader bar (24).

3.2 REGULATOR ASSEMBLY

3.3 Constant-mass-flow regulator assembly (13, see fig. D–36) is attached to manifold valve assembly (12) by means of yoke assembly (22). The regulator fitting provides a connection for control block assembly (14) which delivers gas to the rebreathing system through air inlet block (16).

3.4 Regulatory body (1, see fig. D–37) contains a high-pressure and low-pressure chamber and a nozzle assembly (2). A stainless-steel regulator diaphragm (3) and gasket (4) are located and sealed between the regulator body and diaphragm cap (5). The diaphragm cap encloses a sealed, evacuated bellows assembly (6) with its enclosed main regulator spring. The spring button (7) in the diaphragm cap is used to increase or decrease the pressure of the main regulator spring upon the regulator diaphragm. This alters the pressure which must be overcome in order for gas to pass from the high-pressure to low-pressure chambers of the regulator. The diaphragm cap is perforated, allowing surrounding air or water pressure to act on the external surface of the diaphragm. During underwater use, as water pressure increases with depth, the increase in surrounding water pressure against the external surface of the diaphragm is exactly balanced by the equal rise in the gas pressure against the internal surface of the diaphragm. This gas pressure is transmitted from the control block through the gas delivery tube, and into the regulator low-pressure compartment. However, as water pressure increases with depth, the sealed bellows assembly is compressed and opposes the force of the spring within the bellows, reducing the net force in direct proportion to the water depth. Reduction of the spring pressure against the regulator diaphragm results in the lowering of the gas pressure in the low-pressure compartment of the regulator body. Through this means, changes in diving depths automatically alter the regulator pressure setting in order to accomplish delivery of approximately the same mass of gas mixture regardless of depth.

3.5 GAS CYLINDERS AND MANIFOLD VALVE ASSEMBLY (see fig. D–38)

3.6 Two aluminum cylinders (1), two elbow assemblies (2 and 3), and a manifold valve assembly (4) comprise the cylinders and manifold valve assembly.

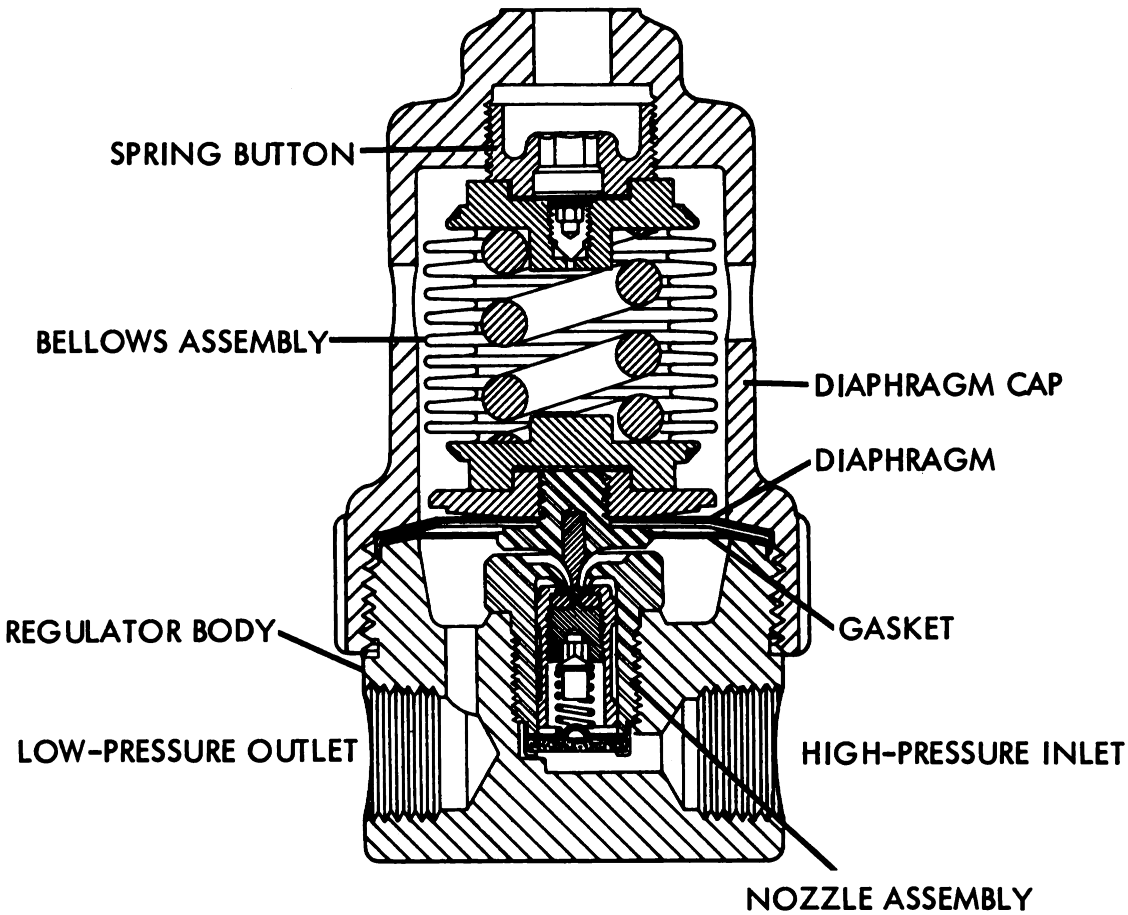


FIGURE D–37.—Regulator assembly.

3.7 The cylinders contain an equivalent of 84 cubic feet of gas at standard conditions when fully charged to 3,000 psi. The two cylinders are hydrostatically tested to 5,000 psi to insure proper service at operating pressure. The bottom of each cylinder is equipped with a stud to accommodate quick-disconnect cylinder spreader assembly (5) which holds the lower end of the cylinders in place.

3.8 The neck of each cylinder is equipped with a right-angle elbow assembly sealed by preformed packings at its junction with the cylinders and terminating in the female component of a ball-and-socket high-pressure joint. Elbow assemblies (2 and 3) are connected through the use of a manifold valve assembly (4). The manifold valve assembly provides fitting (6) for attachment of the constant-mass flow regulator at its yoke assembly, and centrally located shutoff valve (7) which controls the flow of gas from the cylinders to the regulator. The cylinders are charged through fitting (6) of the manifold valve assembly.

3.9 Safety elbow assembly (2) incorporates a safety rupture disk (8) on its outboard end and is designed to capture the rupture disk. The safety rupture disk is preset to rupture at 3,375 to 3,750 psi.

3.10 CONTROL BLOCK ASSEMBLY (see fig. D–39)

3.11 The control block assembly, which is secured to the regulator at the regulator connector, contains an on-off valve (1), a fixed filter and orifice assembly (2), an adjustable needle valve (3) and a jam nut (4), a check valve (5), bypass valve (6), and two fittings for connecting a differential pressure gage.

3.12 Gas enters the control block at regulated pressures through the regulator connector

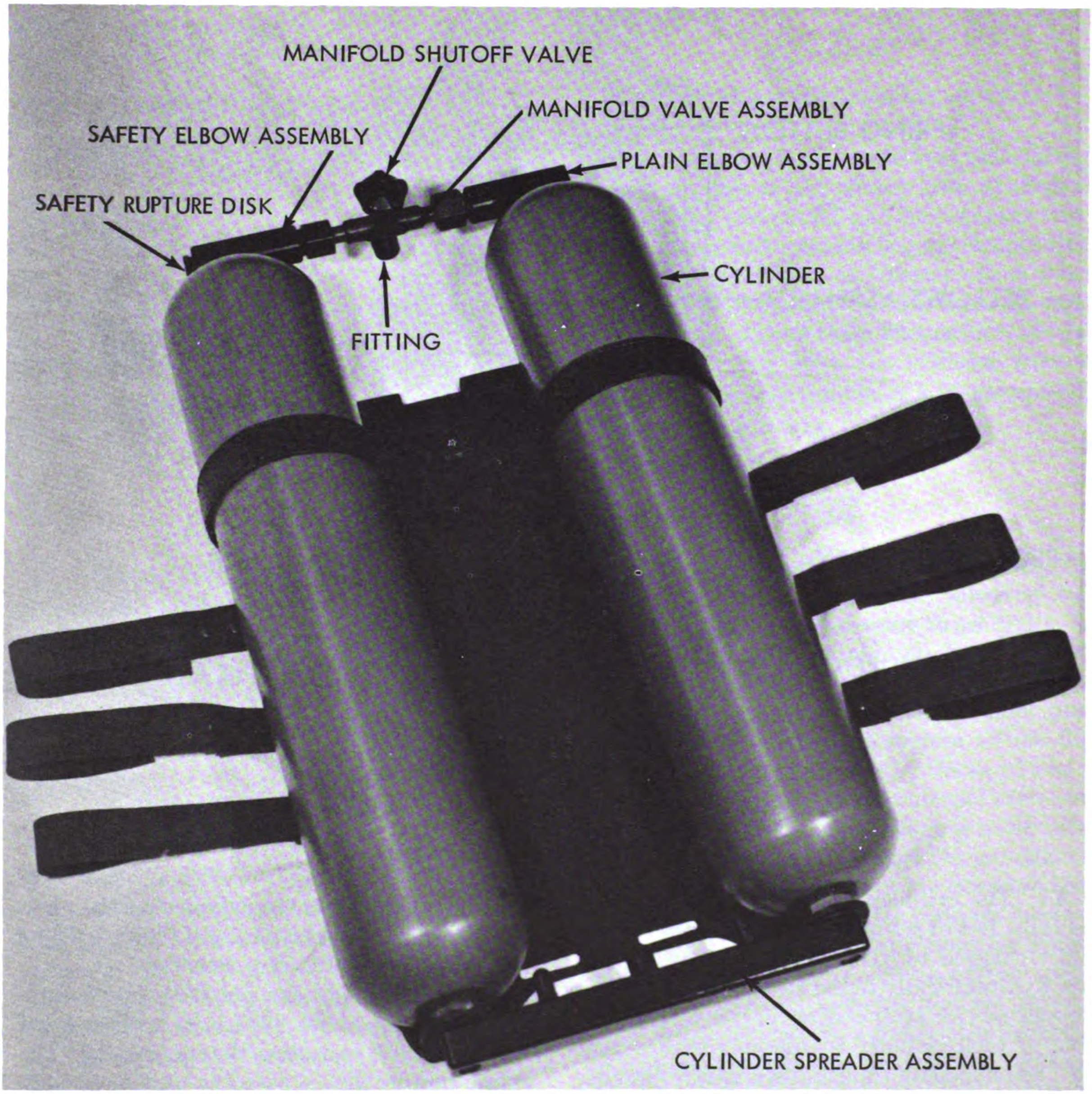


FIGURE D-38.—Cylinders and manifold valve assembly (attached to backplate).

and flows to the closed bypass valve and to the on-off valve. From the on-off valve, gas flows through the filter and orifice assembly to the needle valve. From the needle valve, gas flows through the check valve and control block outlets to the air inlet block on the canister supplying a fresh input of gas to the rebreathing system.

3.13 The filter and orifice assembly provides a means for accurate flow measurement and a continual check of flow rate during a dive utilizing the differential pressure gage.

3.14 The needle valve delivers gas at the proper flow rate and is set according to a schedule for the intended use.

3.15 The bypass valve provides an unrestricted flow of gas for building gas volume during descent, for maintaining comfortable breathing bag volume, for purging during ascent, for emergency inflation of breathing

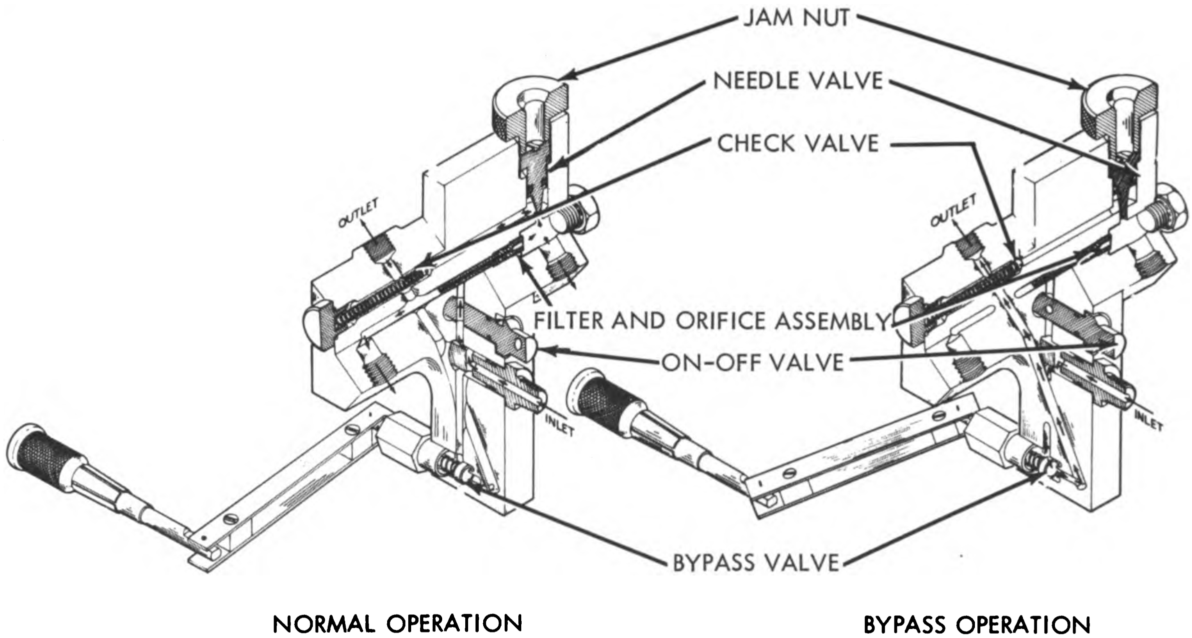


FIGURE D–39.—Control-block assembly.

bags during ascent, and for bypassing normal control block functions if injection failure should occur or in the event that the control block on-off valve is off. The check valve prevents the bypass flow from entering the passage to the needle valve, and to the filter and orifice assembly.

3.16 All connections to the control block assembly are of the quick-disconnect type for ease of maintenance.

3.17 CANISTER ASSEMBLY (see fig. D–40)

3.18 The canister assembly consists of an inner shell (1) and outer shell (2). The outer shell is comprised of two breathing tubes (3 and 4) and an air inlet block (5) at its upper end. A removable cover (6) is secured with a strong back and two screws at its lower end. The inner shell, or inner canister, is located within the outer shell. Approximately 6½ pounds of Baralyme (carbon dioxide absorbent) are contained in the inner canister. A removable screen (7) and gasket (8) are located at the upper end of the inner canister while a screen and spring assembly (9), attached to the canister cover, is located at the lower end of the inner canister.

3.19 Upon exhalation, the left breathing tube (3) connected to the top of the canister assembly carries exhaust gas from the exhalation breathing bag to the canister. The exhaust gas enters the canister and flows between the inner and outer shells. When the gas reaches the bottom of the canister, it flows into the inner canister containing the CO_2 absorbent Baralyme. From the inner canister, the gas flows through the right breathing tube (4) where source gas from the cylinders is added as necessary to replenish the gas supply through the air inlet block via the regulator and control block. The gas then flows to the right, or inhalation breathing bag.

3.20 The canister assembly is secured to the backplate with a slide latch and a quick-disconnect cylinder spreader assembly at the base of the gas cylinders.

3.21 BREATHING BAG AND VEST ASSEMBLY (see fig. D–41)

3.22 The breathing bag and vest assembly consists of inhalation breathing bag (1) and exhalation breathing bag (2) each attached to the vest (3) with six twist-lock fasteners (4). The vest is divided vertically in the front midline and is provided with a zipper (5) enclosure for ease of donning and removal. Each bag extends from behind the neck, over the shoulders, and down over the upper portion of the chest.

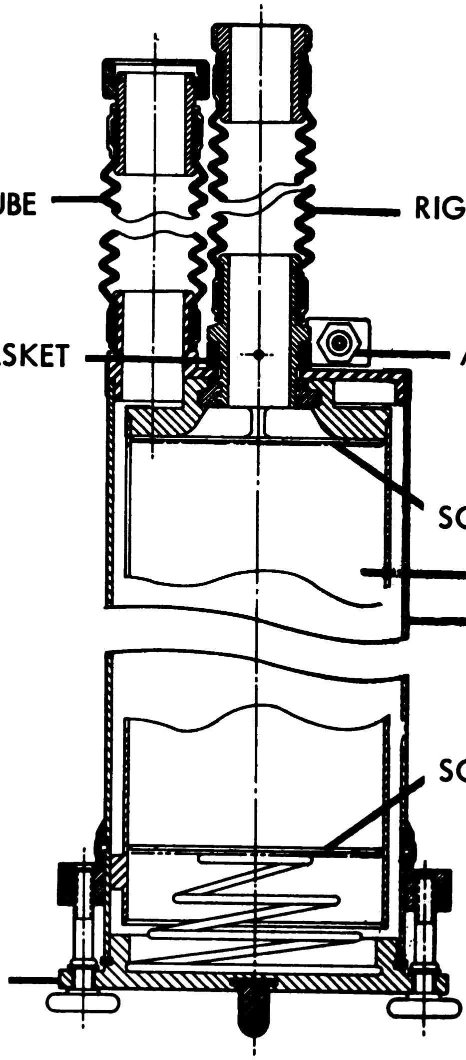


FIGURE D–40.—Canister assembly.

The bags are separated at their upper portion by a circular opening for the head and neck. When inflated, the volume of each breathing bag is approximately 4 liters. A small weight pouch (6), closed with flaps at top and bottom by twist-lock fasteners (7), is located below each breathing bag. Securing bands (8) have also been provided to aid in holding the breathing bags closer to the diver.

3.23 Connecters (9) for the breathing tubes, to and from the mouthpiece T-tube assembly, are securely mounted on the front of each bag at about the level of the neck opening. A second permanently mounted set of breathing-tube connecters (10) extends from the posterior edge of each breathing bag. These connecters provide means for conducting exhaled gas from the exhalation breathing bag to the canister assembly, and from the canister assembly to the inhalation breathing bag. A pocket (11) is provided for retention of differential pressure gage.

3.24 EXHAUST VALVE ASSEMBLY (see fig. D–42)

3.25 The exhaust valve assembly is mounted on the left, or exhalation breathing bag. The major components of the exhaust valve are: valve body (1), diaphragm assembly (2), valve stem assembly (3), a spring (4), washer (5), cover assembly (6), retaining ring (7), adjusting screw (8), and pull grip (9).

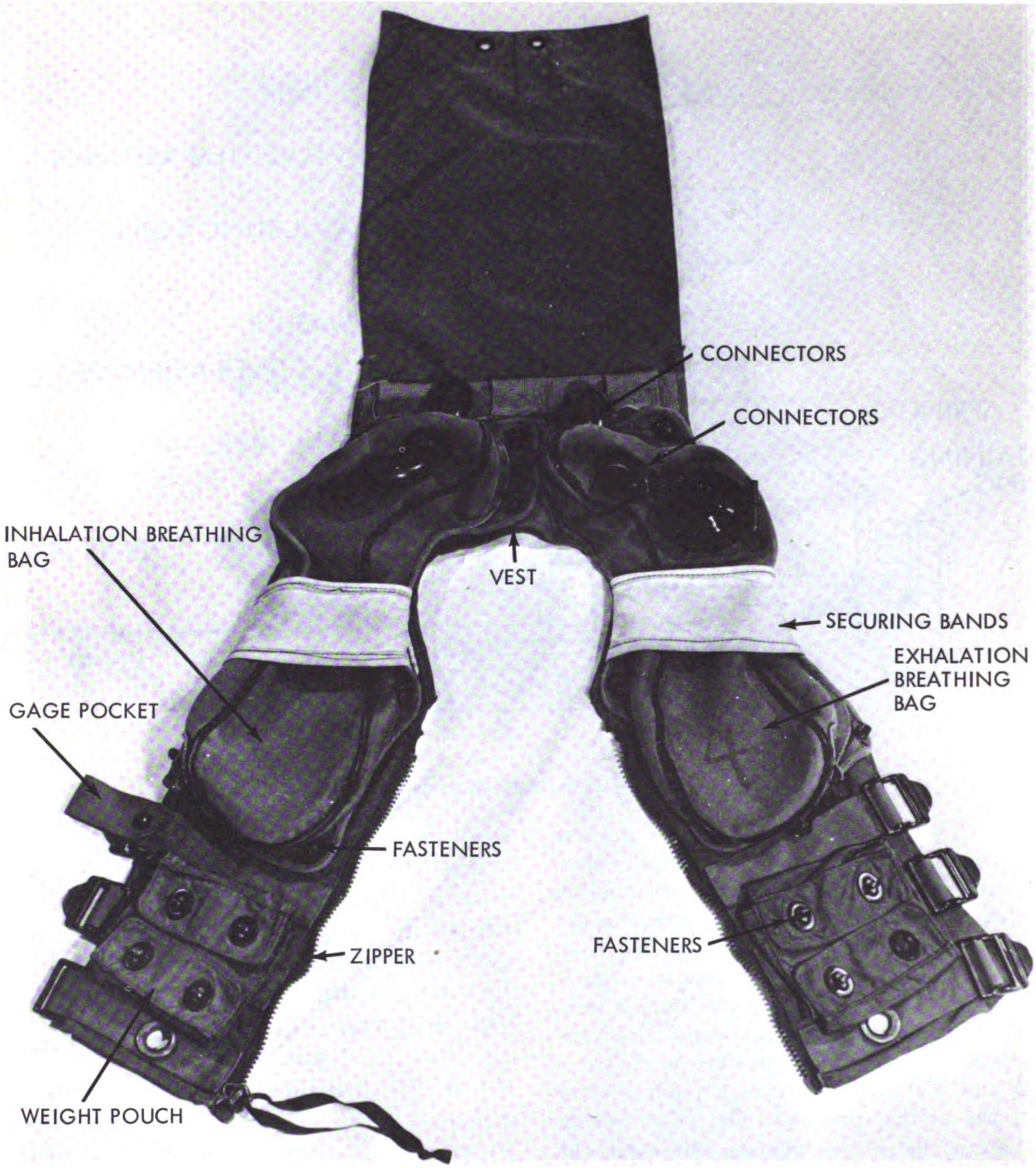


FIGURE D–41.—Breathing bag and vest assembly.

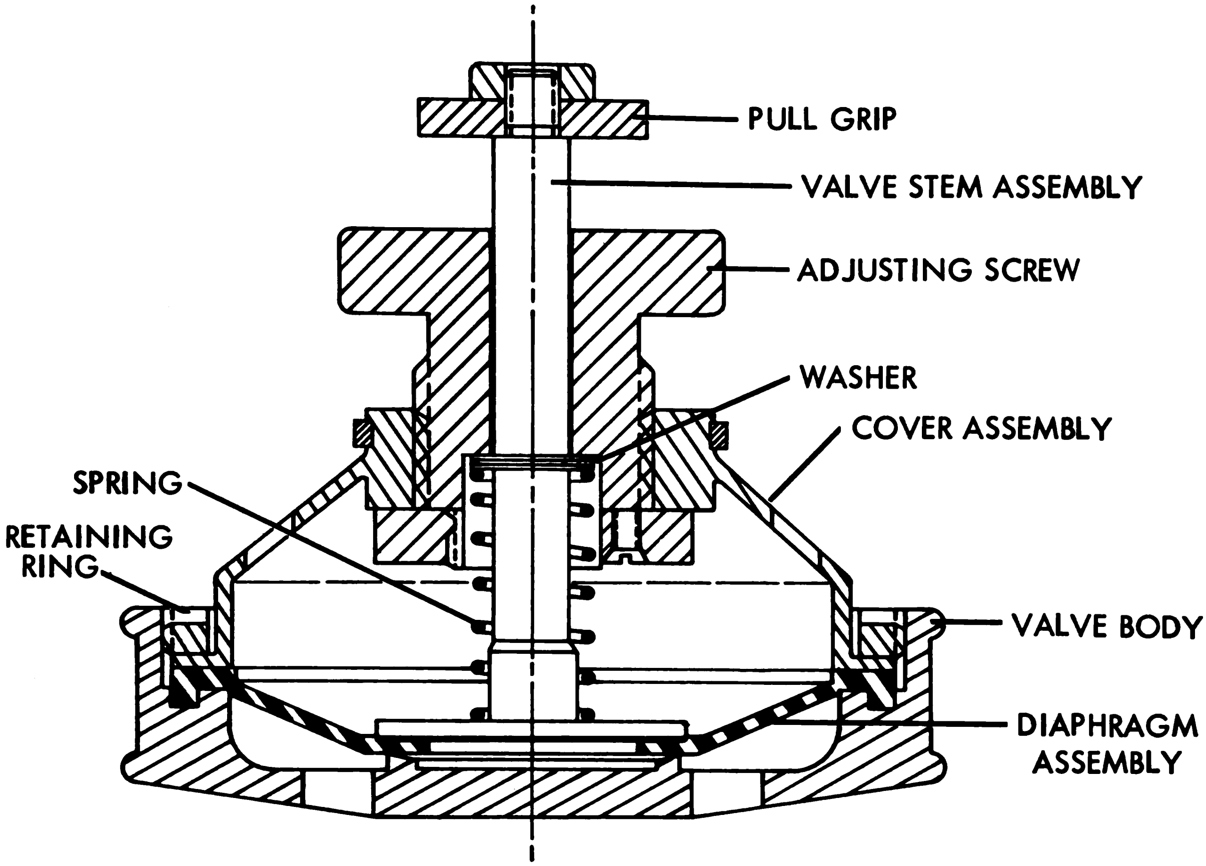


FIGURE D–42.—Exhaust-valve assembly.

3.26 During operation, the adjusting screw compresses the valve spring which applies pressure on the valve stem. The valve stem covers and seats the diaphragm. The gas pressure in the system increases as fresh gas is supplied from the control block. When the system pressure rises above the spring pressure on the diaphragm, the diaphragm unseats and allows gas to escape until the spring pressure on the valve stem and diaphragm reaches a point greater than the system pressure. The valve spring then forces the valve stem down and reseats the diaphragm.

3.27 The exhaust valve setting determines the system pressure. This pressure can be varied from approximately 0.25 psi to 1.0 psi with the adjusting screw. When setting the exhaust valve, the diver regulates the system pressure with the adjusting screw to meet his own requirements. The exhaust valve should be adjusted so that with each exhalation, it releases a small amount of gas. This not only keeps the system pressure relatively constant, but also serves as a warning device for the diver. If the exhaust valve does not release a small amount of gas with each exhalation, it is possible that the liter flow (fresh input of gas) has dropped.

3.28 MOUTHPIECE T-TUBE ASSEMBLY (see fig. D–43)

3.29 The mouthpiece T-tube assembly is composed of two lengths of rubber hose (1 and 2), two check valves (3 and 4) and a mouthpiece and shutoff valve (5). Right hose (1) receives breathing gas from the inhalation breathing bag. Upon inhalation, inhalation check valve (3) permits the breathing gas to enter mouthpiece (5). Upon exhalation, the inhalation check valve (3) closes and the exhalation check valve (4) opens, permitting the exhausted gases to pass through the left hose (2) to the exhalation breathing bag. Mouthpiece shutoff

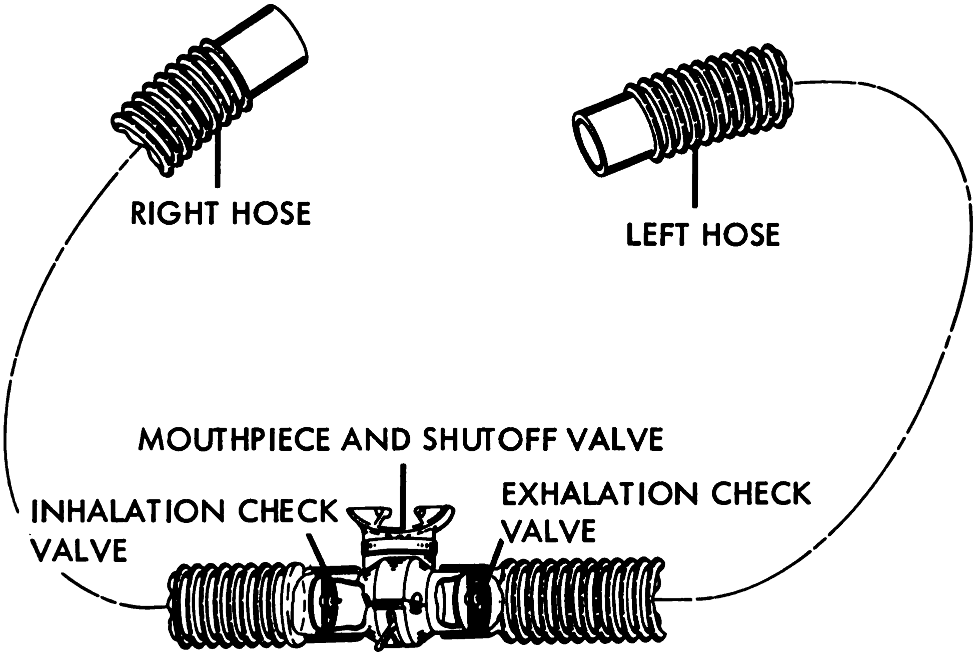


FIGURE D–43.—Mouthpiece T-tube assembly.

valve (5), which has SURFACE and DIVING positions, prevents the entrance of water into the breathing system when in the SURFACE position, and permits inhalation and exhalation through the mouthpiece when in the DIVING position.

SECTION 4 OPERATING INSTRUCTIONS

4.1 PREPARATION FOR USE (see fig. D–36)

4.2 Perform the following operational checks and adjustments prior to using the breathing apparatus:

(*a*) Lay the breathing apparatus on a clean work surface.

(*b*) Remove canister assembly (7) from backplate (18) by removing cylinder spreader bar (24), by disconnecting control block to canister hose (15) at air inlet block (16), by unthreading hoses (25 and 26) from breathing bag and vest assembly (17), and by sliding the canister up and out of lip of backplate (18).

(*c*) Remove regulator assembly (13) and control block assembly (14) from the backplate by disconnecting the pull rod (27), by removing spring (38), and by loosening regulator yoke assembly (22).

(*d*) Recharge cylinders (9) with the proper gas mixture selected for dive as follows (see fig. D–44):

(1) Open manifold shutoff valve (1) to bleed off any gas that may remain in cylinders (2).

WARNING

Avoid all contact with oil and grease. Oil coming in contact with high-pressure connections may result in an explosion. Mixed-gas cylinders should be treated the same as oxygen cylinders. *Use no oil.*

(2) Connect charging line assembly (3) to manifold valve assembly (4).

(3) Slowly open valve of high-pressure gas source and fill cylinders to desired pressure (3,000-psi maximum).

CAUTION

Charge the cylinders at a rate not to exceed 500 psi per minute. Since cylinders will become warm during charging, allow cylin-

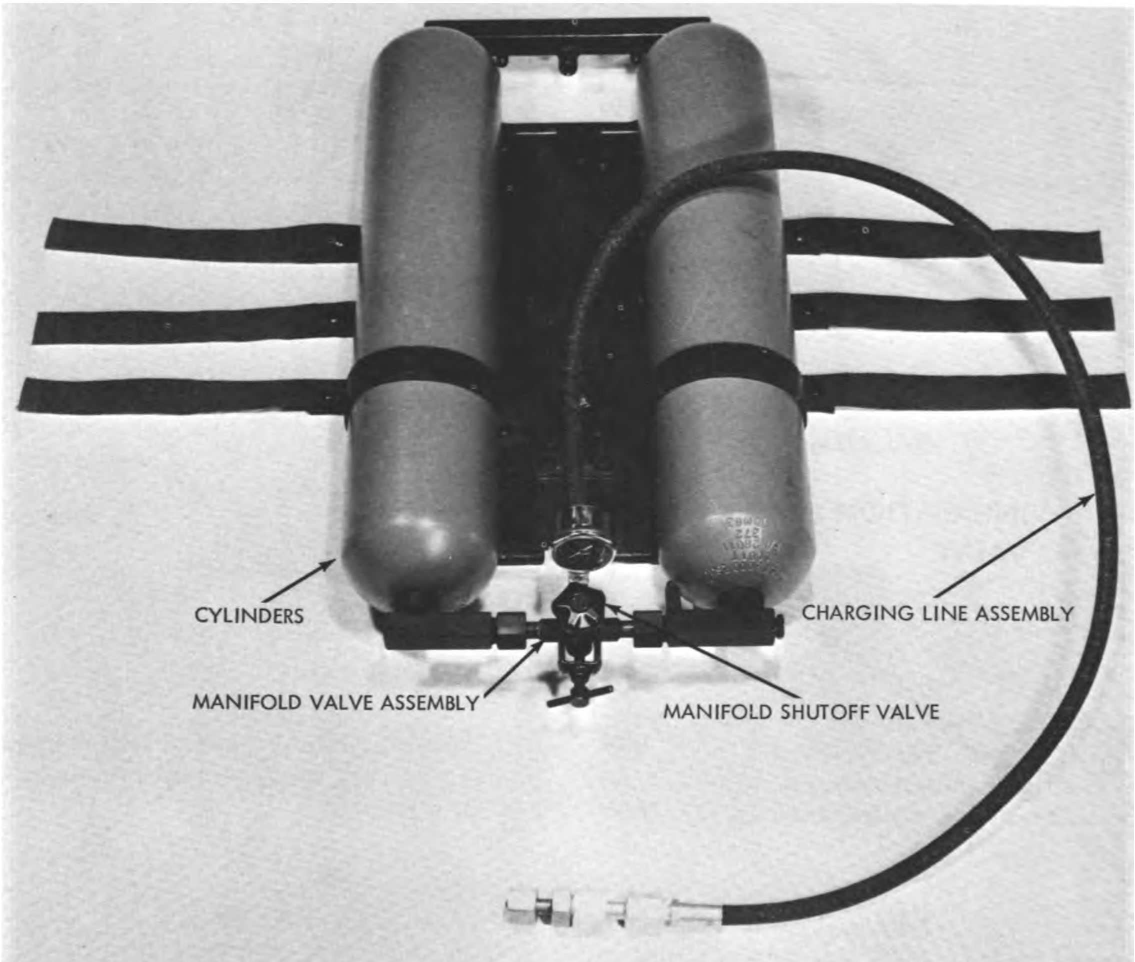


FIGURE D–44.—Cylinder recharging.

ders to cool and complete charging if maximum pressure is desired.

(4) Close manifold shutoff valve (1) and the high-pressure gas source valve. Bleed the charging line assembly at the high-pressure source.

(5) Disconnect charging line assembly (3) from manifold valve assembly (4).

(6) After charging, tag the cylinders to indicate the exact composition of the gas mixture used to fill the cylinders and the pressure to which the cylinders were pressurized.

NOTE

When changing the gas mixture previously used in the cylinders, empty the cylinders and flush thoroughly with a 100-psi charge of the new gas mixture prior to recharging to desired capacity.

(*e*) Remove access cap (28, see fig. D–36) from control block, install appropriate filter and orifice assembly (8, 12, or 21 lpm), and replace the access cap.

NOTE

Visually inspect the filter and orifice assembly for damage before installing in control block. The 12-lpm filter and orifice assembly is supplied with the breathing apparatus. The 8-, 12-, and 21-lpm filter and orifice assemblies are supplied in service kit (see fig. D–56).

(*f*) Fill canister assembly (7, see fig. D–36) with Baralyme pellets as follows:

NOTE

The inner canister must be filled with Baralyme (barium and calcium hydroxides, a commercially available product of Thomas A. Edison, Inc., Stuyvesant Falls, N.Y.).

(1) Turn canister assembly upside down.

(2) Unthread screws (29) and remove canister cover assembly (30).

(3) Visually inspect screen assembly (31) for contamination or damage. If screen assembly is acceptable, place in inner canister.

NOTE

Screen assembly (31) is normally shipped taped to the screen and spring assembly of canister cover assembly (30) to prevent movement of the screen assembly during shipment of empty canister assembly.

(4) Place canister filling collar (2, see fig. D–56 or D–59, fig. D–57) inside the canister to prevent the entrance of Baralyme pellets between the inner and outer canister shells.

NOTE

The canister filling collar is supplied with breathing apparatus in each service kit (see fig. D–56) and in each test kit (see fig. D–57).

(5) Fill the inner canister with Baralyme pellets. Periodically tap the canister assembly while filling to prevent air pockets from forming between the pellets.

(6) Remove the canister filling collar. Replace the canister cover assembly and retain with screws (29, see fig. D–36).

(7) Turn the canister assembly right side up.

(*g*) Secure regulator assembly (13) and control block assembly (14) to the backplate by connecting pull rod (27), and by tightening yoke assembly (22).

(*h*) Secure filled canister assembly (7) to backplate (18) as follows:

(1) Position the canister assembly on the backplate so that the canister is hooked under the lip provided on the backplate.

(2) Replace cylinder spreader bar (24).

(3) Mate control block to canister hose (15) at air inlet block (16).

(4) Connect hoses (25 and 26) to breathing bag and vest assembly (17).

(*i*) Adjust regulator assembly (13) and control block assembly (14) for proper pressure setting and flow requirements as follows (see fig. D–45):

WARNING

Do not attempt to adjust the regulator in any other manner except as outlined below. Other methods of adjustment will result in inaccurate differential pressure gage indications.

(1) Check that manifold shutoff valve (1) and control block on-off valve (2) are off.

(2) Exercise the bypass valve by pulling actuation ring (32, see fig. D–36) several times.

(3) Back off regulator spring button (3, fig. D–45) full counterclockwise using wrench (4). (Wrench (4) is supplied with test kit (see fig. D–57).)

WARNING

Do not attempt to back off on regulator spring button while the regulator is pressurized.

(4) Check that differential pressure-gage fittings (5, fig. D–45) on the control block are plugged.

(5) Disconnect control block to canister hose (6) at air inlet block (7) and connect pressure gage (8) and test hose (9) to end of control block to canister hose (6).

NOTE

Pressure gage (8) should be checked periodically against a master gage. Pressure gage (8) and test hose (9) are supplied with test kit (see fig. D–57).

(6) Place control block on-off valve (2, see fig. D–45) in ON position.

(7) Slowly open manifold shutoff valve (1).

(8) Adjust the regulator at spring button (3) for the required pressure on pressure gage (8) (80 psi, 140 psi, or 180 psi, depending on the filter and orifice assembly used in the control block).

WARNING

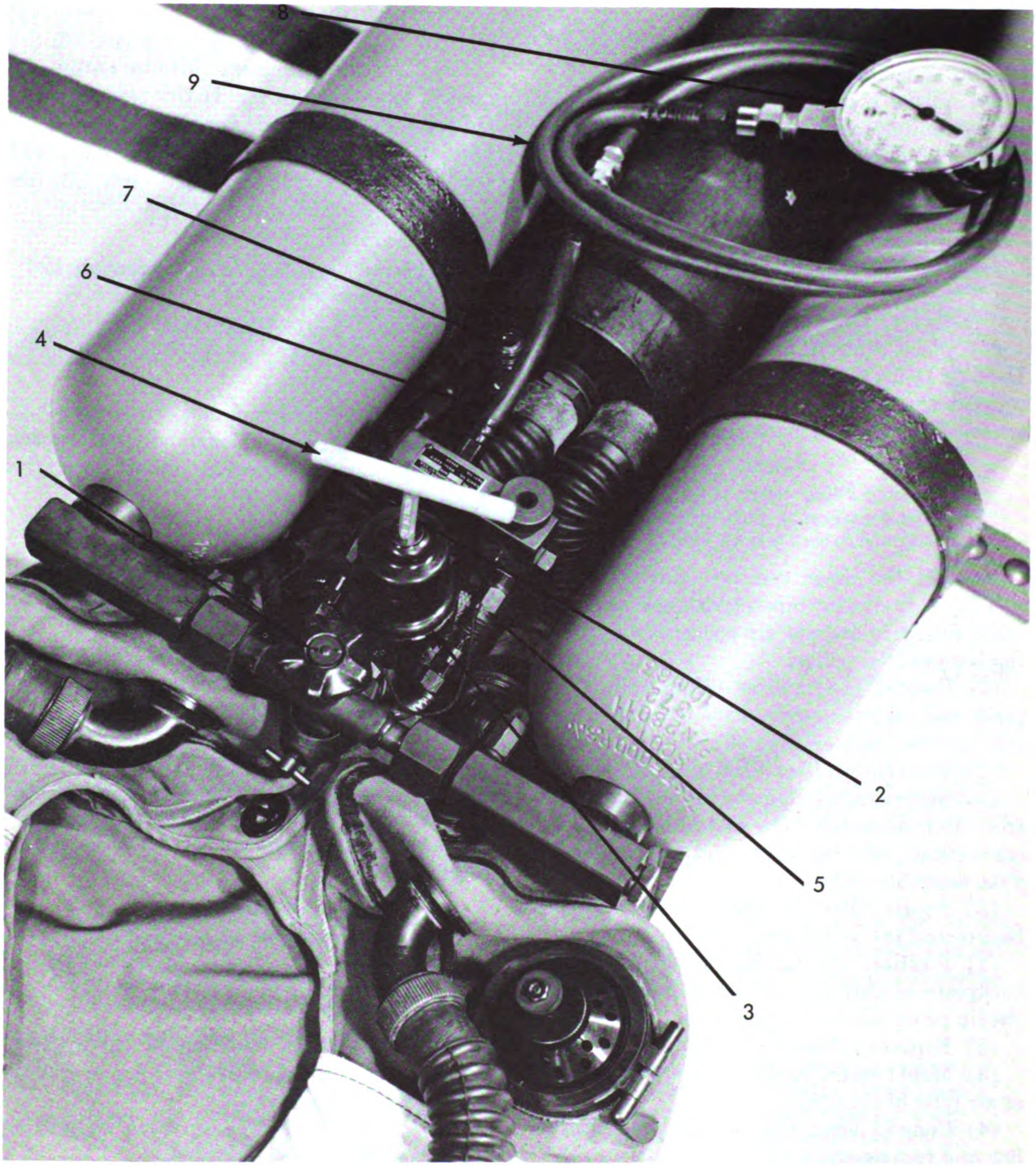
This regulator adjustment is critical and must be accurate. After making the adjustment, allow 2 minutes, then recheck pressure-gage indication. No creepage can be allowed.

(9) Place control block on-off valve (2) in OFF position. Bleed off trapped gas by disconnecting pressure gage (8).

(10) Exercise the bypass valve by pulling the actuation ring several times.

(11) Connect pressure gage (8) to end of test hose (9) and place control block on-off valve in ON position.

(12) Check pressure gage indication. Indication must be identical with indication adjusted for in step (8). If indications are identical, place control block on-off valve in OFF position and remove pressure gage.



1. Manifold shutoff valve
2. Control block ON–OFF valve
3. Spring button
4. Wrench
5. Fittings
6. Control block to canister hose
7. Air inlet block
8. Pressure gage
9. Test hose

FIGURE D–45.—Regulator adjustment.

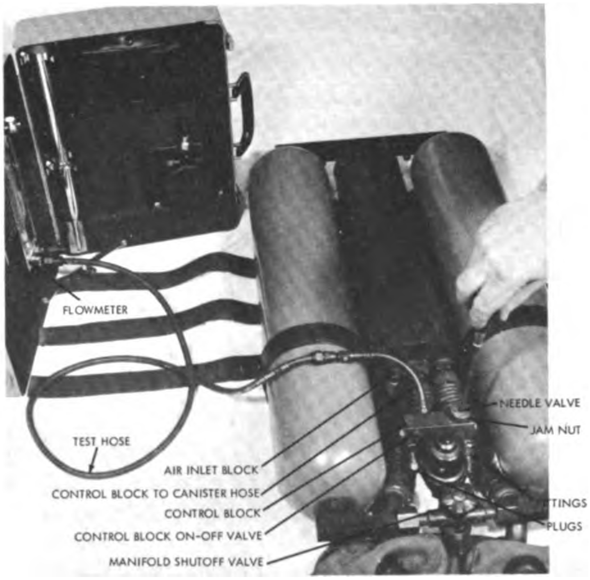


FIGURE D–46.—Central-block adjustment.

(13) After successfully completing steps (1) through (12) above, adjust the liter flow as follows (see fig. D–46):

(a) Check that control block on-off valve (1) is OFF and manifold shutoff valve (2) is open.

(b) Loosen jamnut (3) and turn needle valve (4) down gently until it bottoms out.

NOTE

Use a standard 3/16-inch-tip-width screwdriver to make this adjustment.

(c) Connect end of test hose (5) to appropriate inlet of flowmeter (6).

NOTE

Test hose (5) and flowmeter (6) are supplied in test kit (see fig. D–57).

(d) Place control block on-off valve (1, see fig. D–46) in ON position.

(e) Back off on needle valve (4) and jamnut (3) simultaneously until desired flow is indicated on flowmeter (6).

WARNING

The control-block adjustment is critical and must be accurate. After making the adjustment, allow 2 minutes, then recheck flowmeter indication. No creepage can be allowed.

(f) After adjusting needle valve for required flow, hold needle valve in place with screwdriver and tighten jamnut (3).

NOTE

Tightening of jamnut may necessitate readjustment of needle valve. Repeat steps (a) through (f) until adjustment is made and jamnut secured.

(g) Place control block on-off valve on OFF position.

(h) Remove plugs (7) from control block (8).

(i) Connect the differential pressure gage to control block fittings (9).

(j) Place control block on-off valve in ON position.

(k) Check indication on differential pressure gage. Needle must be in safety area.

(l) Disconnect test hose (5) from flowmeter.

(m) Exercise the bypass valve by pulling actuation ring (32, see fig. D–36) several times.

(n) Connect test hose (5, see fig. D–46) to flowmeter (6) and recheck indication on flowmeter and differential pressure gage.

WARNING

If indication on flowmeter is not identical with original indication or if differential pressure gage does not indicate being in safety area, do not attempt to use the breathing apparatus until the discrepancy is corrected.

(o) Place control block on-off valve in OFF position, disconnect test hose (5) from end of control block to canister hose (10), and connect the control block to canister hose to air inlet block (11).

(*j*) Adjust differential pressure gage (38, see fig. D–50) for correct indication of differential pressure as follows (see fig. D–47):

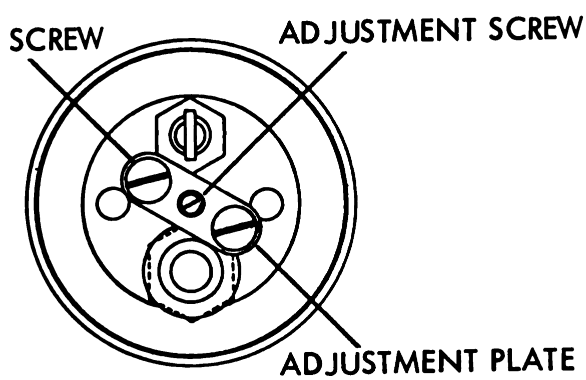


FIGURE D–47.—Differential pressure-gage adjustment.

WARNING

Prior to adjusting the differential pressure gage, insure that the regulator assembly pressure setting and flow requirements are performed as outlined in step (*i*).

(1) Disconnect control block to canister hose (6, see fig. D–45) at air inlet block (7), and connect pressure gage (8) and test hose (9) to end of control block to canister hose (6).

(2) Place control block on-off valve (2) in ON position.

(3) Open manifold shutoff valve (1).

(4) Using test gage, check that correct pressure exists for type of filter and orifice assembly installed.

(5) Loosen screws (3, see fig. D–47) retaining adjustment plate (2).

(6) With screwdriver, turn adjustment screw (1) until gage needle is centered in the safety area (luminescent zone on dial).

(7) Tighten screws (3).

(8) Disconnect test gage and hose; reconnect control block to canister hose.

NOTE

The differential pressure gage may also be bench test calibrated, using a master differential pressure gage. Connect the gages to a suitable test setup and adjust for a 3 psig indication on a master differential pressure gage. Adjust the differential pressure gage as noted in steps *j*(5) through *j*(7).

(*k*) Check the breathing apparatus for leakage by submerging in water. Leakage, as indicated by bubbles, must be corrected prior to use.

(*l*) Check the mouthpiece T-tube assembly as follows:

(1) Place mouthpiece and shutoff valve (5, see fig. D–43) in the DIVING position.

(2) Place the mouthpiece in the mouth, squeeze the inhalation (right) hose closed, and attempt to inhale through the mouthpiece. If it is possible to inhale with the inhalation hose closed off, the check valve is missing or defective. This condition must be corrected prior to using the breathing apparatus.

(3) Squeeze the exhalation (left) hose closed and attempt to exhale through it into the mouthpiece. If it is possible to exhale with the exhalation hose closed off, the check valve is missing or defective. This condition must be corrected prior to using the breathing apparatus.

(4) Place the mouthpiece shutoff valve in the SURFACE position.

(*m*) The breathing apparatus is now ready for use.

4.3 USE OF BREATHING APPARATUS IN DIVING (see fig. D–36)

(*a*) Put on the vest (with all equipment attached and intact) in a normal fashion and zip up. Tighten side straps (20) as desired.

(*b*) Place mouthpiece (1) in mouth, place mouthpiece valve in DIVING position, adjust system exhaust valve assembly (23) and enter the water.

(*c*) Actuate the bypass valve at actuation ring (32) as required during descent.

(*d*) When desired depth has been reached, readjust the exhaust valve as necessary to retain the proper breathing bag (2 and 5) inflation.

(*e*) If it becomes necessary to deflate the breathing bags due to improper exhaust valve adjustment, pull the pull grip (33).

(*f*) If it becomes necessary to inflate the gas bags momentarily, pull bypass valve actuation ring (32).

NOTE

This method of quick inflation may be utilized during emergencies to aid in ascending.

(*g*) After completing a dive, or as necessary, perform the following steps:

(1) Rinse the breathing apparatus in clean, fresh water. Clean all breathing passages with medicated soap.

(2) Remove water drain plugs (34) from bottom of breathing bags and allow water to drain. Allow breathing bag and vest assembly (17) to dry thoroughly.

(3) Remove used Baralyme pellets from canister assembly (7) and rinse entire canister thoroughly.

(*h*) Inspect regulator assembly (13), safety rupture disk (35), and exhaust valve assembly (23) for contamination by foreign matter.

(*i*) When the breathing apparatus is not in use or if it will stand for some time, the following procedure should be used:

(1) Unlatch cylinder straps (21).

(2) Close manifold valve assembly (12).

(3) Exercise the bypass valve at actuation ring (32).

(4) Back off on regulator spring button (7, see fig. D–37).

NOTE

Use wrench (12, see fig. D–57) to back off the regulator spring button.

SECTION 5 MAINTENANCE, OVERHAUL, AND REPAIR

5.1 PREVENTIVE MAINTENANCE

After each use and/or prior to storage, perform the following preventive maintenance procedures on the breathing apparatus (see fig. D–36).

(*a*) Thoroughly rinse the equipment with clean, fresh water until all foreign matter is removed.

(*b*) Inspect regulator assembly (13), regulator aneroid chamber, safety rupture disk (35), and exhaust valve assembly (23) for foreign matter and contamination.

(*c*) Inspect inlet filter of regulator assembly (13) for contamination.

(*d*) Inspect rubber components for deterioration, cuts, and nicks. Replace parts as necessary.

(*e*) Check for smooth operation and return of bypass valve by pulling actuation ring (32).

(*f*) Check that cylinders (9) are charged.

WARNING

Cylinders should be pressurized to approximately 150 psi before storing. Never store the cylinders empty because contamination may result.

(*g*) Inspect all cloth material components for breaks and excessive wear.

(*h*) Unlatch cylinder straps (21) from backplate (18) when breathing apparatus is not in use.

5.2 OVERHAUL AND REPAIR

The following instructions are provided for overhaul and repair of the breathing apparatus:

NOTE

Disassemble components only to the extent necessary to facilitate inspection and repair.

5.3 DISASSEMBLY OF MAJOR COMPONENTS (see fig. D–36)

WARNING

Prior to disassembly make certain cylinders are empty. Open the manifold shutoff valve and crack a high-pressure fitting to release residual pressure.

(*a*) Remove mouthpiece T-tube assembly (36) at fittings of breathing bag and vest assembly (17).

(*b*) Remove the differential pressure gage at control-block quick disconnects.

(c) Remove canister assembly (7) from backplate (18) by removing cylinder spreader bar (24), by disconnecting control block to canister hose (15) at air inlet block (16), by unthreading hoses (25 and 26) from breathing bag and vest assembly (17), and by sliding canister up and out of lip of backplate (18).

(*d*) Remove regulator assembly (13) and control-block assembly (14) from the backplate by disconnecting pull rod (27), by removing spring (38), and loosening yoke assembly (22).

(*e*) Remove cylinders (9) and manifold valve assembly (12) from backplate (18) by unlatching cylinder straps (21), and by sliding cylinder and manifold assembly up and out of backplate.

(*f*) Remove toggle pin assembly (19) to separate the backplate from breathing bag and vest assembly (17).

(*g*) Remove exhaust-valve assembly (23) from the breathing-bag and vest assembly by loosening and removing the exhaust-valve clamp.

5.4 COMPONENT ASSEMBLY

Disassemble the major components using the exploded view illustrations (see figs. D–49 through D–58) and breakdowns (pars. 6.1 through 6.11) as a guide, especially noting the following:

(*a*) Use wrench (16, see fig. D–57) and handle assembly (9) to remove diaphragm cap (9, see fig. D–53).

(*b*) Use manifold valve wrench (15, see fig. D–57) to remove handwheel (4, see fig. D–52).

(*c*) Use elbow spanner wrench (13, see fig. D–57) if removal of elbows (24 and 25, fig. D–55) is required.

(*d*) Use exhaust-valve spanner wrench (14, see fig. D–57) to remove exhaust-valve retaining ring (10, see fig. D–55).

5.5 CLEANING

Clean the breathing apparatus as follows:

(*a*) Wipe off dirt and foreign particles with a clean, lint-free cloth, or blow with clean oil-free air or nitrogen.

(*b*) Dip metal parts which have become contaminated with grease in a container of clean trichloroethylene, Specification MIL–T–7003, and blow dry with a stream of clean, dry, oil-free air or nitrogen.

WARNING

Use normal precautions when handling trichloroethylene. Prolonged inhalation of fumes or exposure to the skin may be harmful to the operator.

(*c*) Clean rubber parts with soap and water. Clean all breathing passages with medicated soap. Rinse with clean water and allow to air dry.

WARNING

All breathing passages must be thoroughly cleaned and dried to prevent fungus of the lungs.

5.6 INSPECTION

Inspect parts as follows prior to reassembly:

(*a*) Carefully inspect all metal parts for cracks, nicks, dents, burrs, and tool marks.

(*b*) Inspect all rubber parts for cracks, distortion, and other signs of wear or aging.

(*c*) Inspect all threaded areas for burrs or other damage.

(*d*) Inspect bellows assembly for loose internal spring, cracks, dents, or other damage which could cause failure or leakage.

(*e*) Inspect all filters for contamination and corrosion.

(*f*) Inspect all quick disconnects for proper functioning.

5.7 LUBRICATION

To lubricate, use Fluorolube, grade S–30 (manufactured by Hooker Electrochemical Co., Niagara Falls, N.Y.), or an equivalent lubricant which conforms to applicable military specifications, on all preformed packings. No other lubrication of the breathing apparatus is required.

WARNING

Do not allow oil, grease, flammable solvents, or other combustible materials to come in contact with parts that will be exposed to pressurized oxygen. Such materials as well as dust, lint, and fine metal filings are all potential combustibles. When exposed to oxygen under pressure, these materials might ignite and explode.

5.8 REPAIR

Repair of parts is not recommended. However, the following repairs may be conducted:

(*a*) Repair minor defects in threaded areas by chasing.

(*b*) Refinish dull (black) parts as necessary according to Specification MIL–F–495.

5.9 COMPONENT REASSEMBLY

Reassembly is essentially the reverse of disassembly. Reassemble the major components using the exploded-view illustrations (see figs. D–49 through D–58) and breakdowns (par. 6.1 through 6.11) as a guide, especially noting the following:

NOTE

Coat all preformed packings with Fluorolube, Grade S–30 (manufactured by Hooker Electrochemical Co., Niagara Falls, N.Y.), or an equivalent, prior to reassembly.

(*a*) Check that all preformed packings and other sealing components are properly positioned.

(*b*) Use exhaust valve spanner wrench (14, see fig. D–57) to tighten exhaust-valve retaining ring (10, see fig. D–55).

(*c*) Use elbow spanner wrench (13, see fig. D–57) to tighten elbows (24 and 25, see fig. D–55) to breathing bag and vest assembly.

(*d*) Use manifold valve wrench (15, see fig. D–57) to replace handwheel (4, see fig. D–52).

(*e*) Use wrench (16, see fig. D–57) and handle assembly (9) to tighten diaphragm cap (9, see fig. D–53).

5.10 COMPONENT TESTING

5.11 Canister assembly leak test (see fig. D–48) is as follows:

(*a*) Suitably adapt a low-pressure line (1), a regulator (2), and an air source to canister air-inlet block (3).

(*b*) Mate canister hoses (4 and 5).

(*c*) Pressurize canister assembly (6) to 3 psi.

(*d*) Submerge the canister assembly in water and check for leakage. No leakage must be evident.

(*e*) After test, disconnect the test setup at the canister air-inlet block and separate canister hoses. Dry the canister assembly thoroughly.

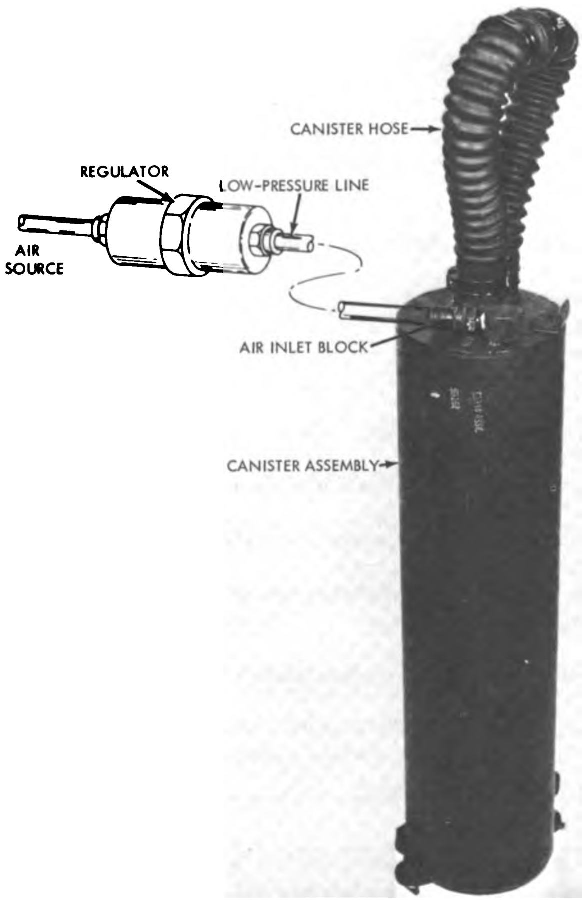


FIGURE D–48.—Canister leak-test setup.

5.12 To perform the breathing bag and vest assembly leak test—

(*a*) Suitably cap the connectors (9 and 10, see fig. D–41) and the exhaust valve assembly.

(*b*) Remove the drain plugs from exhalation breathing bag (2) and from inhalation breathing bag (1).

(*c*) Apply 3-psi air supply to the drain-plug connections.

(*d*) Check the breathing bags for leakage by submerging in water if necessary.

(*e*) After test, remove the air supply, remove the plugs from the connectors and the exhaust valve, and thoroughly air-dry the breathing bag and vest assembly.

5.13 REASSEMBLY OF MAJOR COMPONENTS (see fig. D–36)

(*a*) Position backplate (18) on cylinders (9) and manifold valve assembly (12), and secure in place with cylinder straps (21).

(*b*) Secure backplate (18) to breathing bag and vest assembly (17) using toggle pin assembly (19).

(*c*) Secure regulator assembly (13) and control block assembly (14) to the backplate by tightening yoke assembly (22) and connecting pull rod (27).

(*d*) Position canister assembly (7) on backplate (18) and secure with cylinder spreader bar (24). Connect control block to canister hose (15) at air-inlet block (16), and thread hoses (25 and 26) to fittings of breathing bag and vest assembly.

(*e*) Connect the differential pressure gage or plugs (37) to quick-disconnect fittings of control block assembly (14).

(*f*) Thread mouthpiece T-tube assembly (36) to fittings of breathing bag and vest assembly.

5.14 TROUBLESHOOTING

See figure D–49 for troubleshooting chart.

FIGURE D–49.—*Troubleshooting Chart*

Symptom	Probable cause	Possible remedy
	Mouthpiece T-tube assembly	
High inhalation resistance	Contaminated or faulty inhalation check valve (3, see fig. D–43).	Clean or replace inhalation check valve.
High inhalation and exhalation resistance.	Mouthpiece and shutoff valve (5) not in DIVING position.	Place valve in DIVING position.
High exhalation resistance	Contaminated or faulty exhalation check valve (4).	Clean or replace exhalation check valve.
Leakage at hose connections	Improper connections	Tighten connections.
	Exhaust valve assembly	
Leakage	Contamination	Disassemble and clean valve.
	Loose clamp assembly	Tighten clamp assembly.
	Broken or weak spring (11, see fig. D–55).	Replace spring.
	Deteriorated or cut diaphragm assembly (6).	Replace diaphragm assembly.
	Regulator assembly	
No output	Manifold shutoff valve (7, see fig. D–38) closed.	Open valve.
Restricted flow	Contaminated inlet filter (2, see fig. D–53).	Clean or replace filter.
Unable to adjust properly	Damaged first-stage components or bellows assembly (3).	Inspect and replace parts as necessary.
Leakage through diaphragm cap (9, see fig. D–53).	Deteriorated or cut diaphragm assembly (7) or top diaphragm gasket (8).	Replace parts as necessary.
No depth compensation	Punctured or broken bellows assembly (3).	Replace bellows assembly.
Leakage at inlet	Faulty inlet seal	Tighten yoke assembly or replace preformed packing (1, see fig. D–52).
	Cylinder and manifold valve assembly	
Leakage at neck of cylinders (7, see fig. D–50).	Faulty preformed packing (4)	Replace preformed packing.
Leakage at manifold connections	Loose fittings	Tighten fittings.
	Damaged fittings	Replace manifold valve assembly (16, see fig. D–50) or defective elbow assembly.
Leakage at manifold shutoff valve	Damaged or scored valve seat	Replace retainer assembly (8, see fig. D–52).
	Faulty gasket (5, see fig. D–52)	Replace gasket.
	Loose or damaged diaphragm cap (9, see fig. D–53).	Tighten or replace diaphragm cap.

FIGURE D–49.—*Troubleshooting Chart*—Continued

Symptom	Probable cause	Possible remedy
Control block assembly		
Unable to obtain proper system flow.	Needle valve (16, see fig. D–54) not properly adjusted.	Adjust needle valve.
	Incorrect or damaged filter and orifice assembly.	Change or replace filter and orifice assembly.
Leakage at bypass valve	Faulty preformed packing (3), gasket (10), or spring (9).	Replace defective parts as necessary.
	Worn or scored valve seat	Replace valve stem assembly (15).
Leakage at access caps	Faulty preformed packings (4 and 6)	Replace preformed packings.
Leakage at fittings	Loose or damaged couplings (13 and 29).	Tighten or replace as necessary.
Canister assembly		
Leakage at bottom end of canister.	Loose cover assembly (3, see fig. D–51) or faulty sealing gasket (13).	Tighten cover and/or replace sealing gasket.
Leakage at upper end of canister	Faulty sealing gasket (14)	Replace sealing gasket.
	Loose or damaged hose clamp assemblies (18).	Replace hose clamp assemblies as required.
	Air inlet block (16) loose	Tighten air inlet block.
Breathing bag and vest assembly		
Leakage at breathing bags	Loose elbow(s) (24 and 25, see fig. D–55).	Tighten elbow(s).
	Loose band assembly (26)	Tighten band assembly.
	Water drain plugs (22) not secure	Tighten plugs.
	Damaged breathing bag(s) (20 and 21).	Replace breathing bag(s).

SECTION 6 PARTS LIST

This parts list includes identification data covering all units and their maintenance parts to facilitate ready identification of the parts for replacement and ordering purposes (see figs. D–50 through D–58).

6.1 LIST OF UNITS

Part No.	Description	Quantity	Figure reference
26202	Mouthpiece T-tube assembly	1	Fig. D–50.
55100	Canister and tank assembly	1	Figs. D–51 through D–56.
55300	Breathing bag and vest assembly	1	Fig. D–57.
58350–01	Service kit	1	Fig. D–58.

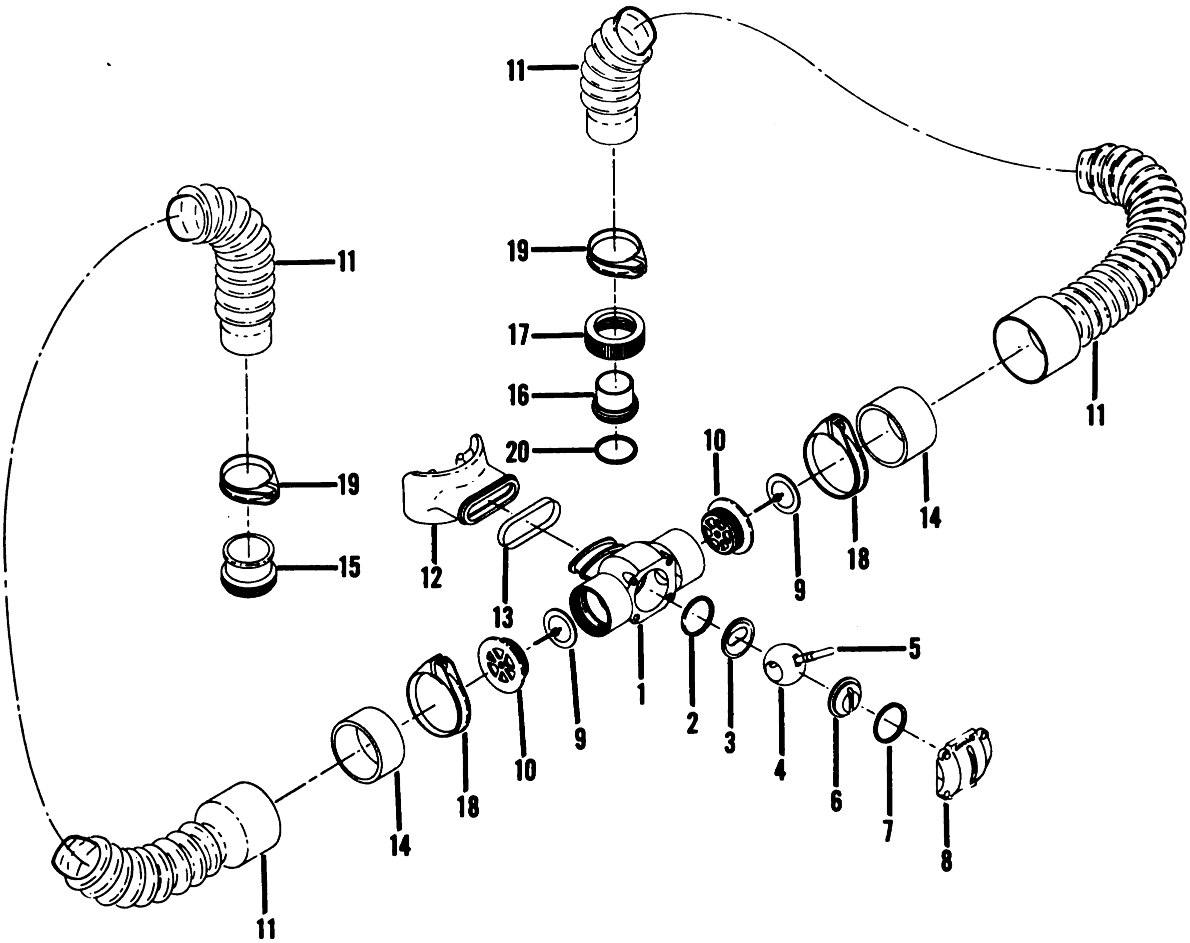


FIGURE D-50.—Mouthpiece, T-tube assembly.

6.2 MAINTENANCE PARTS LIST FOR MOUTHPIECE T-TUBE ASSEMBLY (see fig. D–50)

Part No.	Index No.	Description	Quantity
26202–1	1	Body	1
26202–2	2	Gasket	1
26202–3	3	Ring, valve retainer	1
26202–4	4	Valve	1
26202–5	5	Lever	1
26202–6	6	Ring, outer	1
26202–7	7	Gasket	1
26202–8	8	Cover	1
26202–10	9	Valve, check	2
26202–11	10	Holder, valve	2
26202–12	11	Hose	2
26202–13	12	Bit, mouthpiece	1
26202–14	13	Retainer, mouthpiece	1
26202–16	14	Sleeve	2
26202–18	----------	Hose assembly, male (refer to items 11, 15, and 19 for breakdown)	1
26202–19	----------	Hose assembly, female (refer to items 11, 16, 17, 19, and 20 for breakdown).	1
26202–20	----------	Valve assembly (refer to items 4 and 5 for breakdown)	1
55333	15	Fitting, hose, male	1
55334	16	Fitting, hose, female	1
55338	17	Nut, hose connection	1
800594	18	Clamp assembly	2
800595	19	Clamp assembly	2
10001384	20	Gasket	1

6.3 MAINTENANCE PARTS LIST FOR CANISTER AND TANK ASSEMBLY (see fig. D-51)

Part No.	Index No.	Description	Quantity
AN505B416-8	1	Screw, machine	2
AN6227-7	2	Packing, preformed	2
AN6227-8	3	Packing, preformed	1
AN6290-12	4	Packing, preformed	2
6553-3	5	Plug, safety	1
6555	6	Washer, sealing	1
28011-01	7	Cylinder, mixed-gas	2
28011-02	8	Stud	2
55103		Toggle pin assembly (refer to items 9, 14, and 24 for breakdown)	1
55104	9	Rod	1
55150	10	Fitting, male	2
55173	11	Strap, body	6
55184	12	Dust tube, tank	2
55186	13	Disk, bursting	1
55216	14	Lock	1
55229	15	Elbow, safety	1
55230	16	Elbow, plain	1
55295	17	Canister assembly (refer to par. 6.4 and fig. D-52 for breakdown)	1
55297		Safety plug assembly (refer to items 5, 6, and 13 for breakdown)	1
55328	18	Manifold valve assembly (refer to par. 6.5 and fig. D-53 for breakdown).	1
55330	19	Backplate	1
55347	20	Pull rod assembly	1
55355		Elbow assembly, manifold, plain (refer to items 12 and 16 for breakdown).	1
55356		Elbow assembly, manifold, safety (refer to items 5, 6, 12, 13, and 15 for breakdown).	1
55360	21	Pin, spring	1
55379	22	Connecter	1
55393	23	Grommet	2
55395		Cylinder spreader assembly (refer to items 24 through 27 for breakdown).	1
55396	24	Bar, spreader	1
55397	25	Lockpin	2
55398	26	Handle, lockpin	2
55399	27	Spring, lockpin	1
56850		Cylinder strap assembly (refer to items 28 through 30, 32, and 33 for breakdown).	2
56851	28	Strap	1
56852	29	Clamp	1
56853	30	Bracket	1
56855	31	Regulator and yoke assembly (refer to par. 6.6 and fig. D-53 for breakdown).	1
56889-56	32	Pin	1
56889-70	33	Pin	1
56895	34	Nut, connecter	1
57253	35	Packing, preformed	2
57360-00	36	Socket assembly	2
58340	37	Control block assembly (refer to par. 6.7 and fig. D-55 for breakdown).	1
800330-01		Differential pressure gage and hose assembly (refer to items 10, 36, and 38 through 40 for breakdown).	1
800345-01	38	Gage assembly, differential pressure	1
800352-00	39	Hose assembly, male	1
800353-00	40	Hose assembly, female	1
10001393	41	Spring	1

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6.4 MAINTENANCE PARTS LIST FOR CANISTER ASSEMBLY (see fig. D-52)

Part No.	Index No.	Description	Quantity
AN6227-3	1	Packing, preformed	2
55159	2	Screen assembly	1
55165	3	Cover assembly, canister	1
55166	4	Screw, cover	2
55168	5	Screen and spring assembly	1
55170	6	Fitting, hose	1
55251	7	Tube, flexible	2
55333	8	Fitting, hose, male	1
55334	9	Fitting, hose, female	1
55338	10	Nut, hose connection	1
55343	11	Canister assembly, inner	1
55344	12	Canister assembly, outer	1
55365	13	Seal	1
55368	14	Gasket	2
55369		Hose assembly, male (refer to items 7, 8, and 18 for breakdown)	1
55370		Hose assembly, female (refer to items 7, 9, 10, 18, and 19 for breakdown).	1
55371	15	Washer, cover screw	2
55382	16	Block, air inlet	1
57360-00	17	Socket assembly	1
800595	18	Clamp assembly	4
10001384	19	Gasket	1

6.5 MAINTENANCE PARTS LIST FOR MANIFOLD VALVE ASSEMBLY (see fig. D-53)

Part No.	Index No.	Description	Quantity
AN6227-10	1	Packing, preformed	1
8391	2	Washer	1
55178	3	Bonnet	1
55180	4	Handwheel	1
55335	5	Gasket	1
56858	6	Spring, helical, compression	1
57409	7	Stem, valve	1
57411	8	Retainer assembly	1
57493	9	Body, nipple, and nut assembly	1
57494	10	Locknut	1

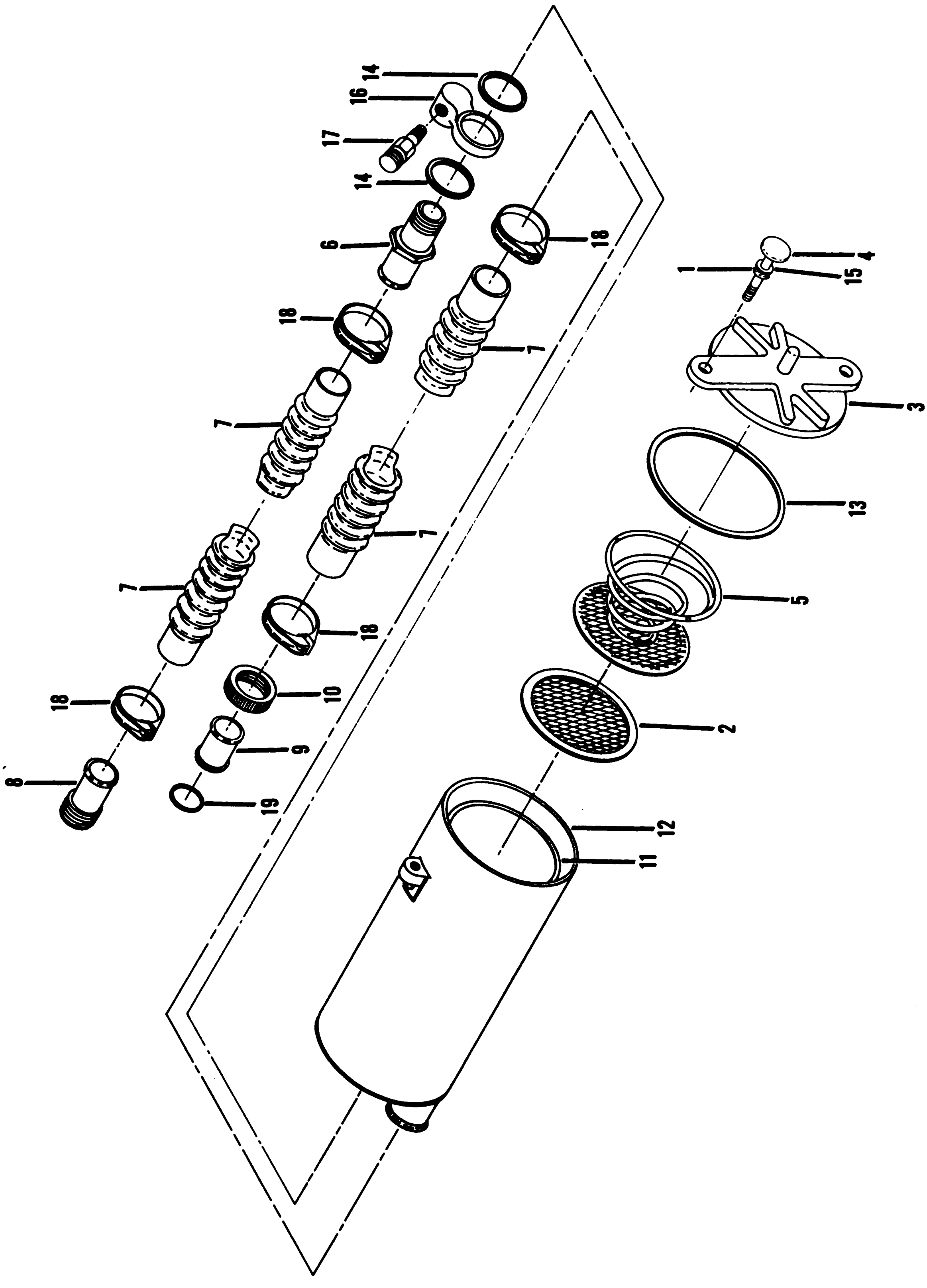

FIGURE D–52.—Canister assembly.

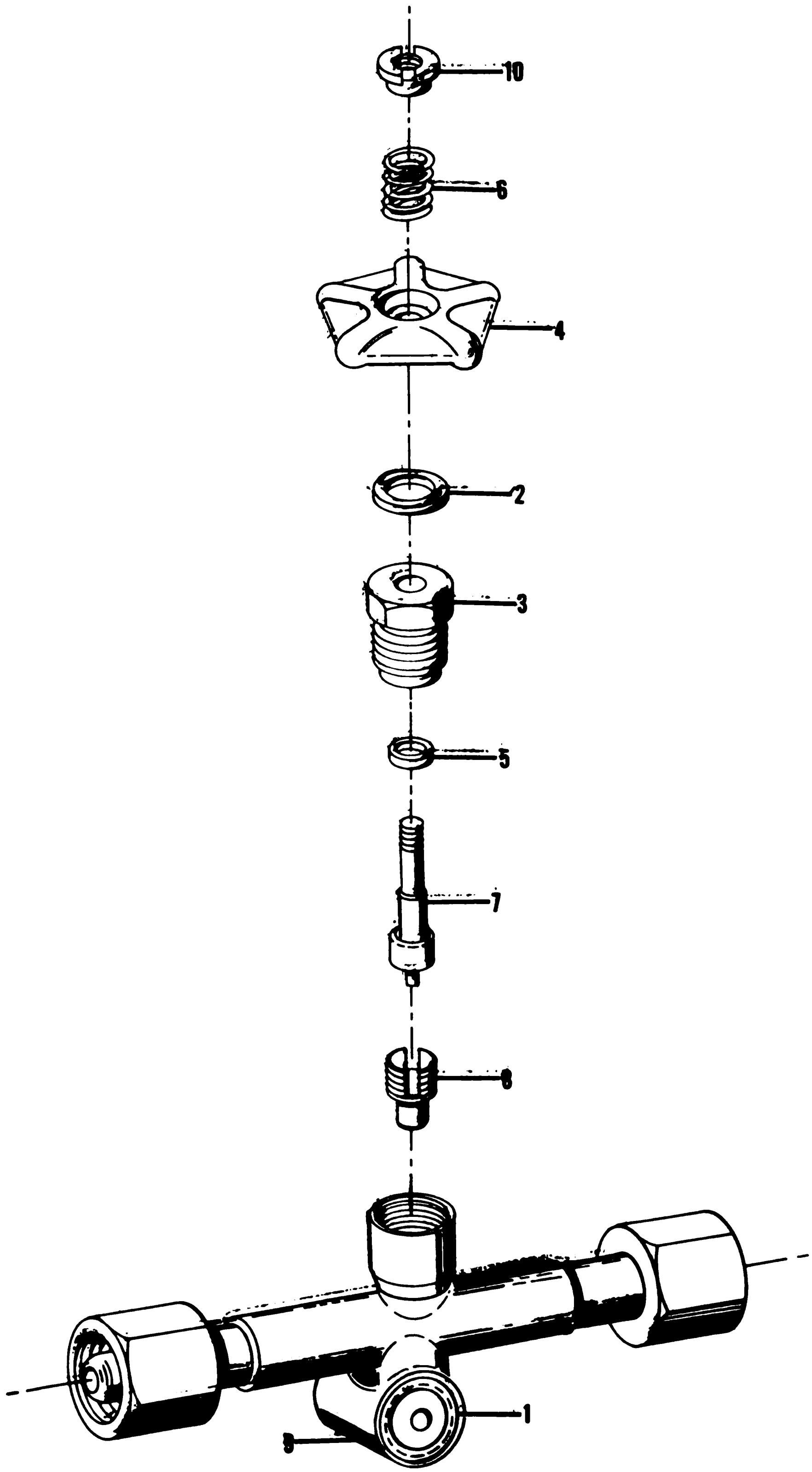

FIGURE D–53.—Manifold-valve assembly.

6.6 MAINTENANCE PARTS LIST FOR REGULATOR AND YOKE ASSEMBLY (see fig. D–54)

Part No.	Index No.	Description	Quantity
AN150389	1	Pin, straight, headless	1
13728	2	Filter, screen	1
55298		Regulator assembly (refer to items 3, and 5 through 10 for breakdown).	1
55322	3	Bellows assembly	1
56854		Yoke handle assembly (refer to items 1 and 4 for breakdown)	1
56854–1	4	Body	1
57334	5	Nozzle assembly	1
57376	6	Button, spring	1
57378	7	Diaphragm assembly	1
57379	8	Gasket, diaphragm	1
57495	9	Cap, diaphragm	1
57496	10	Body, regulator	1
58341		Yoke assembly (refer to items 1, 2, 4, 11, and 12 for breakdown)	1
58342	11	Connecter	1
58343	12	Yoke	1

6.7 MAINTENANCE PARTS LIST FOR CONTROL BLOCK ASSEMBLY (see fig. D–55)

Part No.	Index No.	Description	Quantity
AN505B6–6	1	Screw, machine	2
AN6227–1	2	Packing, preformed	1
AN6227–2	3	Packing, preformed	2
AN6227–5	4	Packing, preformed	3
MS28778–6	5	Packing, preformed	1
MS29512–3	6	Packing, preformed	2
55128	7	Ball, check	1
55130	8	Cap, access	2
55141	9	Spring, helical, compression	1
55142	10	Gasket, valve cap	1
55145	11	Cap, bypass valve	1
55148	12	Coupling	1
55150	13	Coupling, male	1
55156	14	Plug	1
55346	15	Valve stem assembly	1
55377	16	Valve, needle	1
55378	17	Nut, jam	1
55383	18	Plug, male	1
55384	19	Cap, female	1
55388	20	Plate, bypass lever	1
55390	21	Lever pin and body assembly	1
55391	22	Link, bypass pull rod	1
55392	23	Retainer, bypass pull rod	1
56857	24	Valve assembly	1
56860	25	Spring, helical, compression	1
56866		Hose assembly, control block to canister (refer to items 12, 14, 26, and 27 for breakdown).	1
56867	26	Ferrule	2
56868	27	Hose	1
56869	28	Ring, retaining	1
57360–00	29	Socket assembly	1
58335	30	Control block	1
58338–01	31	Filter and orifice assembly	1
58344	32	Plate, identification	1

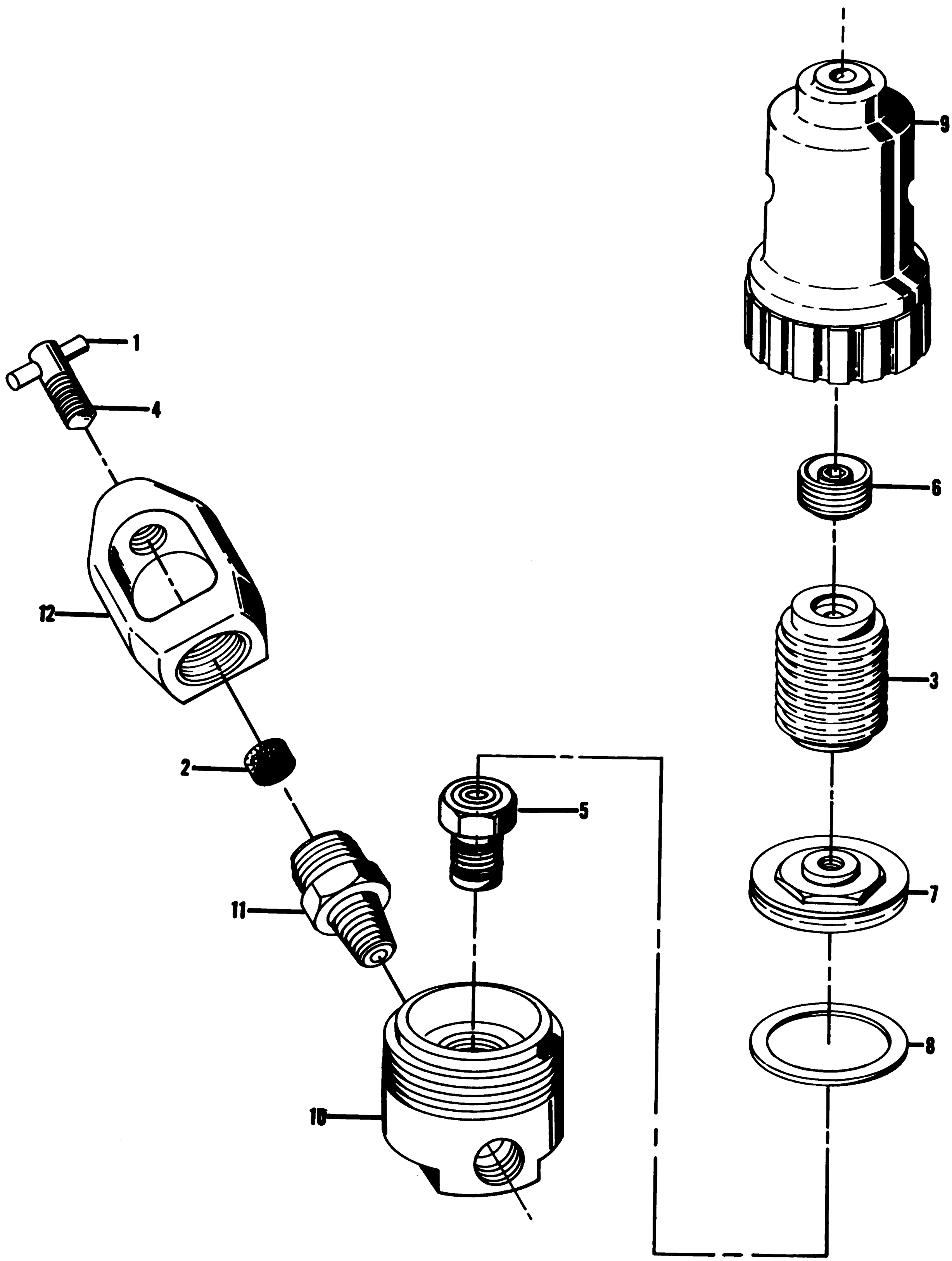

FIGURE D–54.—Regulator and yoke assembly.

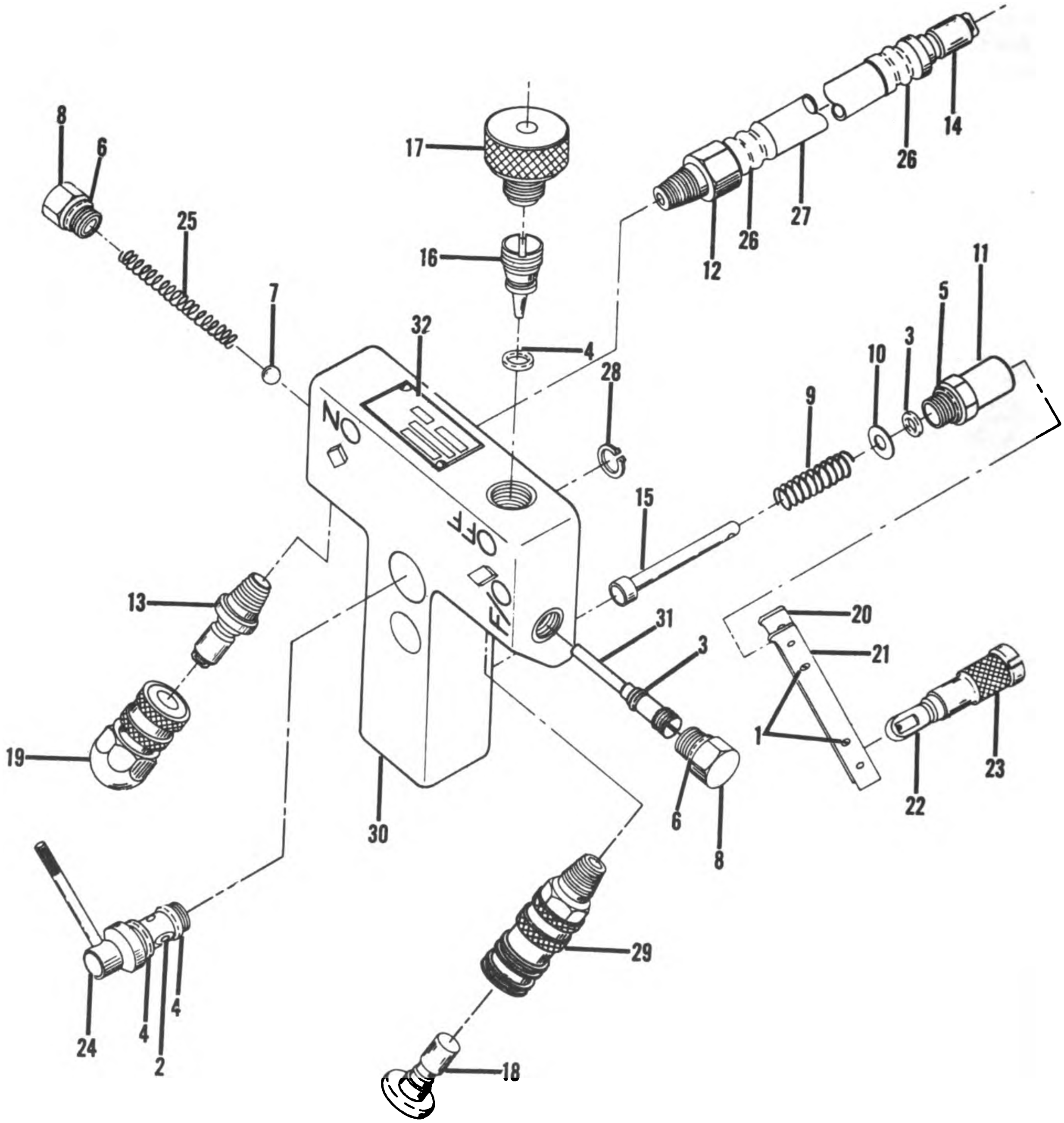

FIGURE D–55.—Control-block assembly.

6.8 MAINTENANCE PARTS LIST FOR BREATHING BAG AND VEST ASSEMBLY (see fig. D–56)

Part No.	Index No.	Description	Quantity
55242	1	Drain assembly, water	2
55248	2	Nut and guard assembly	4
55249	3	Washer	4
55250	4	Nut	4
55252	5	Exhaust valve holder	1
55268	6	Diaphragm assembly	1
55269	7	Washer, stop	1
55272	8	Screw, adjusting	1
55273	9	Cover	1
55274	10	Ring, retaining	1
55275	11	Spring, helical, compression	1
55276	12	Washer	AR
55278	13	Pull grip	1
55279	14	Nut	1
55280		Clamp assembly, exhaust valve (refer to items 15, 16, 26, and 27 for breakdown).	1
55281	15	Screw, clamp	1
55283	16	Plate, thumb	1
55287	17	Stem assembly	1
55288	18	Body, valve	1
55299–07		Breathing bag and vest assembly (refer to items 1, 5, and 19 through 22 for breakdown).	1
55299–09	19	Vest assembly	1
55299–11	20	Breathing bag assembly, left	1
55299–13	21	Breathing bag assembly, right	1
55302		Exhaust valve assembly (refer to items 6 through 14, and 17, 18, and 28 for breakdown).	1
55327	22	Cap assembly, water drain	2
55338	23	Nut	2
55340	24	Elbow, hose	2
55342	25	Elbow, hose	2
55345		Cover assembly (refer to items 7 through 9, and 28 for breakdown)	1
55350		Elbow assembly, female (refer to items 2 through 4, 23, 24, and 29 for breakdown).	2
55351		Elbow assembly, male (refer to items 2 through 4, and 24 for breakdown).	2
56872	26	Band assembly	1
56873		Clamp screw assembly (refer to items 14, 15, and 27 for breakdown)	1
56874	27	Pin, spring	1
10001381	28	Band, retaining	1
10001384	29	Gasket	1

6.9 MAINTENANCE PARTS LIST FOR SERVICE KIT (see fig. D–57)

Part No.	Index No.	Description	Quantity
AN6227–2	1	Packing, preformed	3
55295–T52–1	2	Collar, canister filling	1
58338–00	3	Filter and orifice assembly	1
58338–01	4	Filter and orifice assembly	1
58338–02	5	Filter and orifice assembly	1

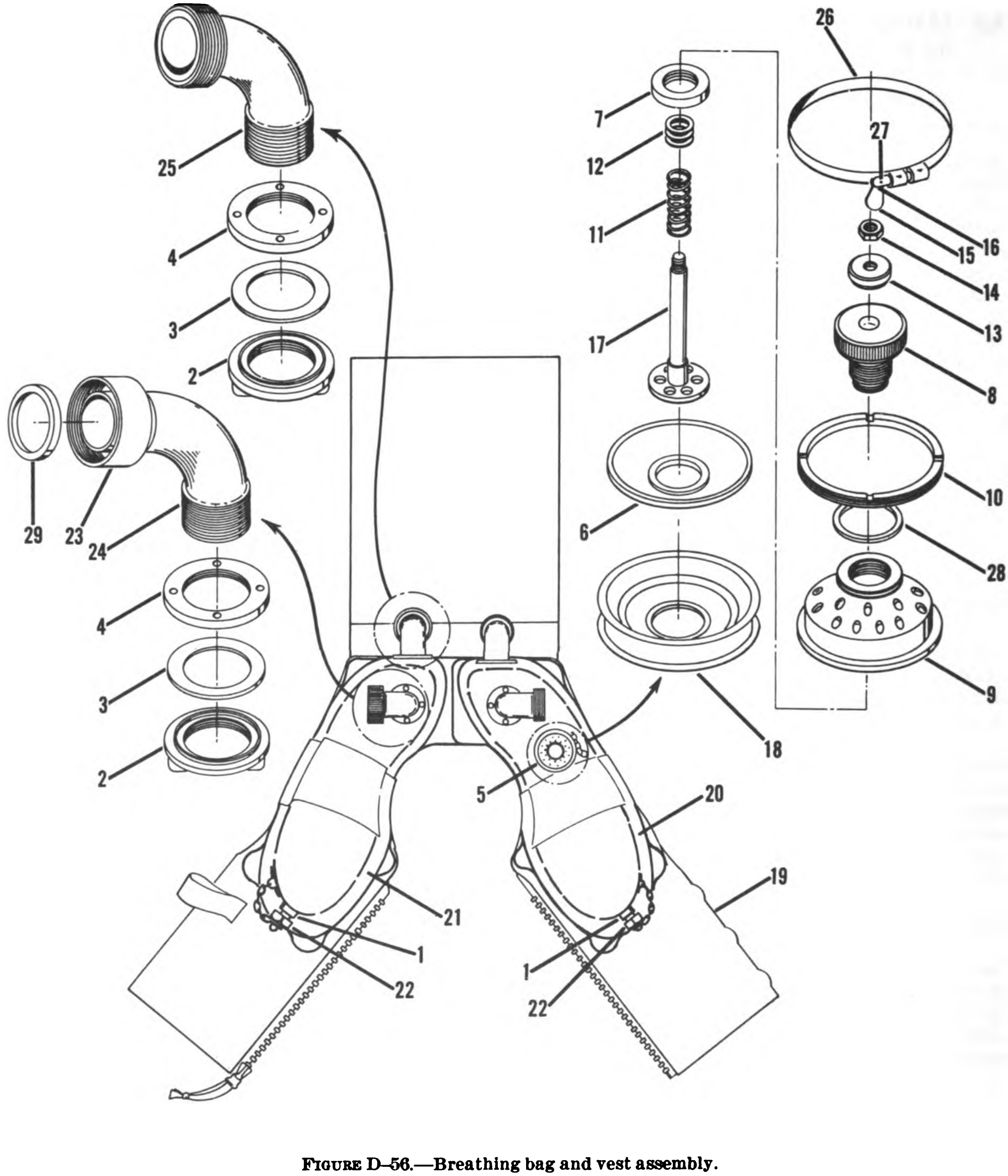

Figure D–56.—Breathing bag and vest assembly.

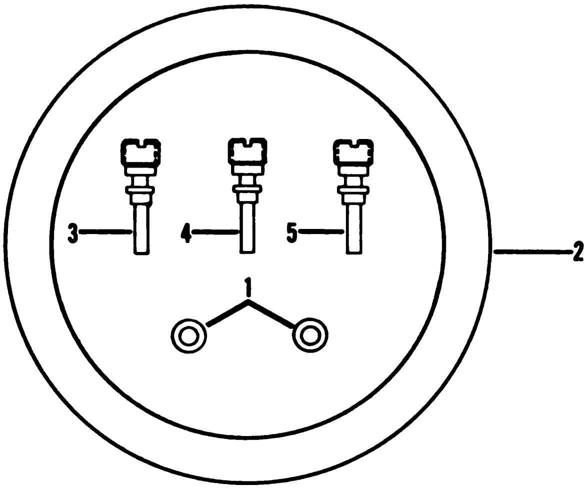

FIGURE D–57.—Service kit.

6.10 PARTS LIST FOR TEST KIT ASSEMBLY, PART NO. 28651–01 (see fig. D–58)

Part No.	Index No.	Description	Quantity
AN227-6B	1	Button	4
AN227-7B	2	Socket	4
AN227-8B	3	Stud	2
13915	4	Clip	2
29701-1	5	Case assembly	1
29705-1	6	Hose assembly	1
29717-1	7	Test gage assembly	1
29720-1	8	Flowmeter assembly	1
29776-1	9	Handle assembly	1
29777	10	Pad, tape	1
55295-T52-1	11	Collar, canister filling	1
55298-T91-1	12	Wrench, regulator adjustment	1
55300-T91-1	13	Spanner wrench, elbow	1
55302-T91-1	14	Spanner wrench, exhaust valve	1
55328 T91-1	15	Wrench, manifold valve	1
56892	16	Wrench	1
56894	17	Eyelet	2
800572-00	18	Gage holder assembly	1
800609-00		Kit assembly, tool holder (refer to items 11 through 16, and 19 for breakdown).	1
800610-00	19	Tool-holder assembly	1
10001245	20	Flowmeter calibration chart	1

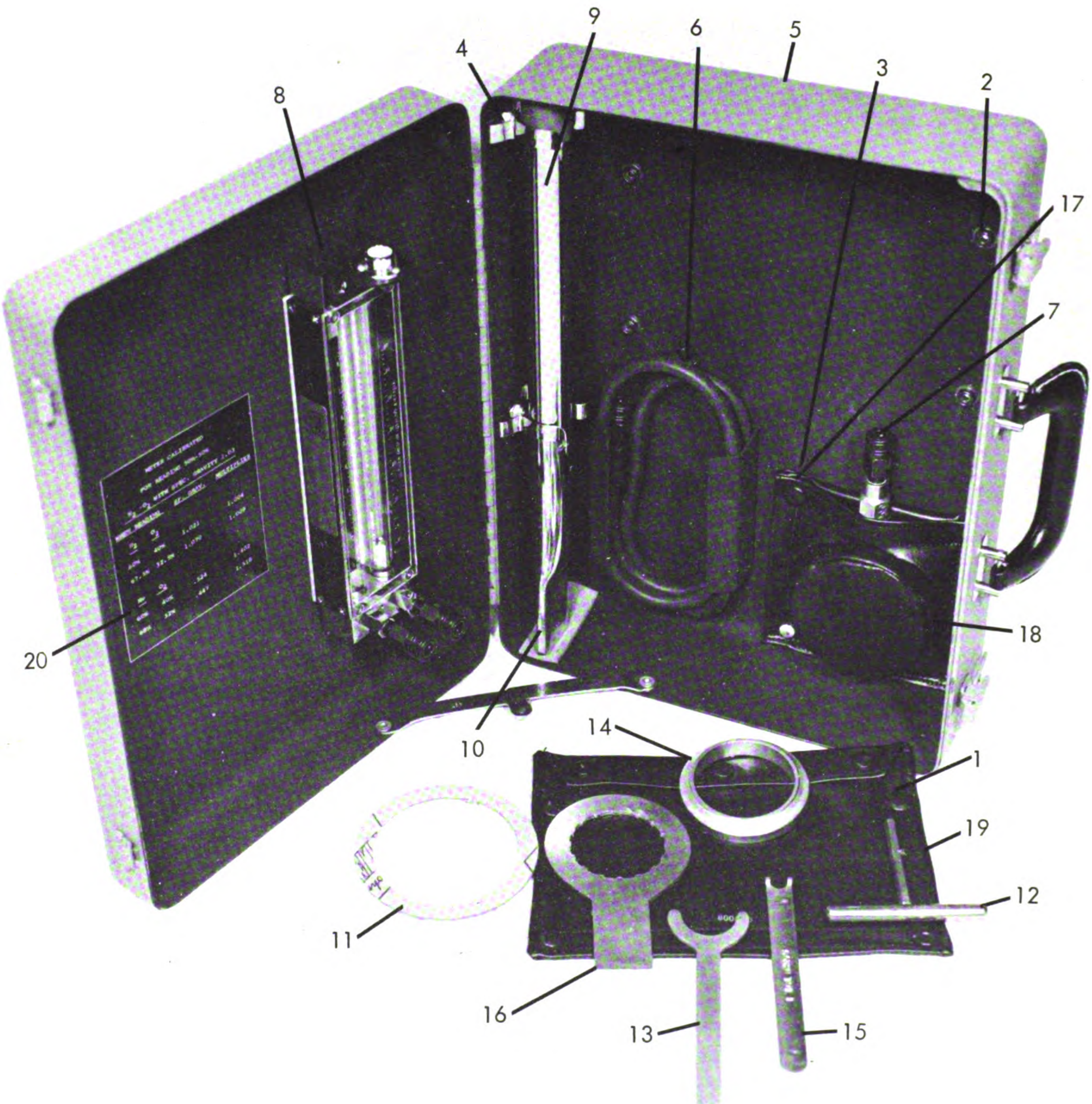

FIGURE D–58.—Test-kit assembly.

6.11 PARTS LIST FOR CHARGING LINE ASSEMBLY PART NO. 56887–1 (see fig. D–59)

Part No.	Index No.	Description	Quantity
6176–72	1	Hose assembly	1
6441	2	Coupling assembly, oxygen	1
13445	3	Pressure gage (3,000 psi)	1
13728	4	Filter, screen	1
56854	5	Handle, yoke	1
56883–1	6	Coupling assembly, nitrogen	1
56912–1	7	T	1
58341		Yoke assembly (refer to items 4, 5, 8, and 9 for breakdown)	1
58342	8	Connecter	1
58343	9	Yoke	1

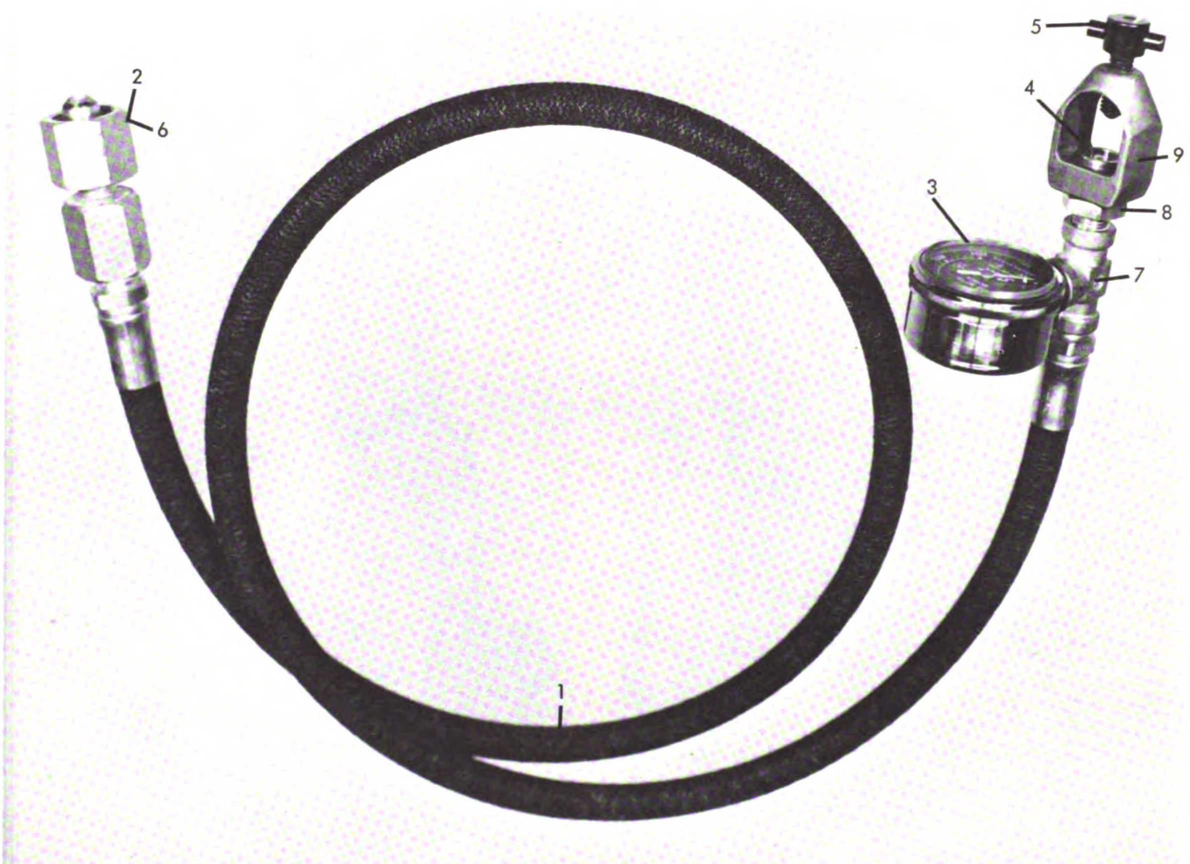

FIGURE D–59.—Charging line assembly.

SECTION 7 MODIFICATION FOR OXYGEN DECOMPRESSION

7.1 The Mk VI breathing apparatus can be easily modified for oxygen decompression as shown in figures D–60, D–61, and D–62. The conversion requires that a standard oxygen cylinder and regulator from the U.S. Navy oxygen closed-circuit apparatus be attached to the Mk VI. The oxygen supply hose is then connected to the drain valve of the inspiratory breathing bag. When the oxygen decompression stops are reached, the mixed-gas supply is secured, the oxygen valve is opened, and the bags are purged three times with oxygen. The tables allow 2 minutes for this procedure, which is a limit not difficult to achieve. The alternative for oxygen decompression is to have a surface-supplied source of oxygen at the decompression stops, rather than to modify the equipment. However, it is best to modify the equipment if oxygen decompression is anticipated, because the diver may not be able to locate the surface-supplied oxygen system in all cases.

FIGURE D–60.—Mk VI, modified for oxygen decompression (front view).

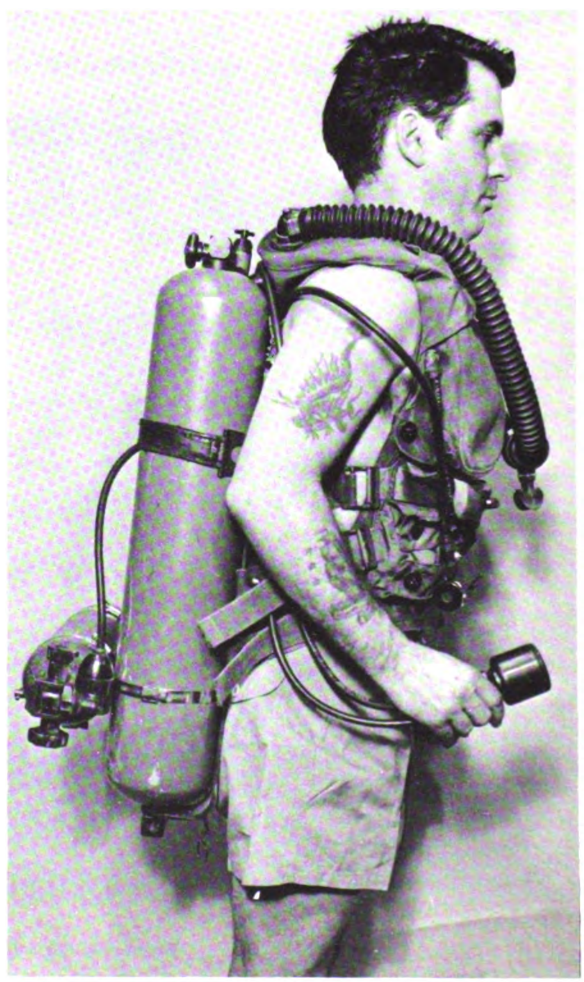

FIGURE D–61.—Mk VI, modified for oxygen decompression (right side).

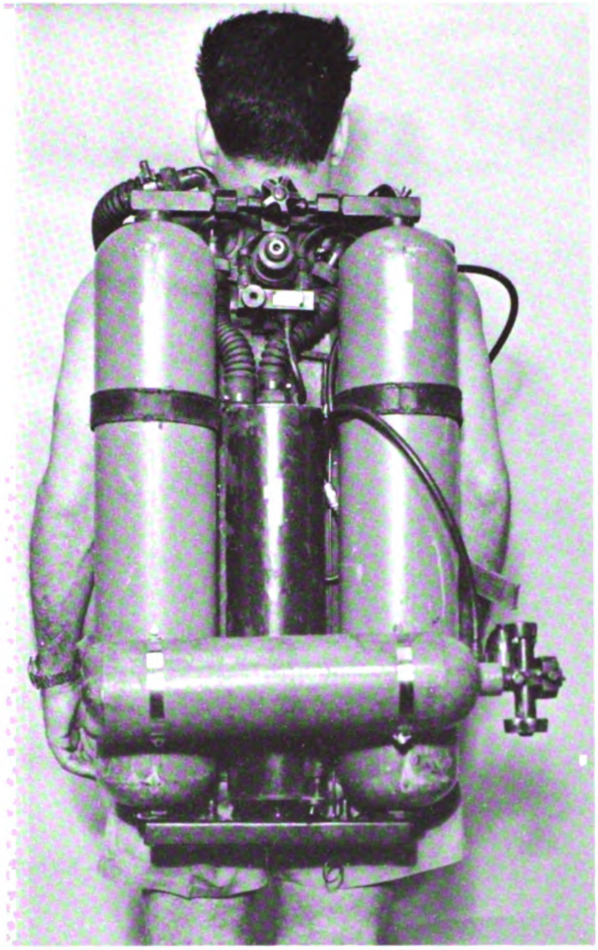

FIGURE D–62.—Mk VI, modified for oxygen decompression (rear view).

U.S. NAVY DIVING MANUAL

APPENDIX E

MARINE LIFE

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CONTENTS

ILLUSTRATIONS

TABLES

MARINE LIFE

(1) Of the thousands of forms of animal and plant life to be found in the ocean, there are relatively few that constitute a real hazard to the diver. However, some species are dangerous and may in some instances inflict serious wounds, poisoning, or violent death. Most difficulties can be prevented if the diver is made sufficiently aware of potential problems. Marine-life hazards of concern to the diver consist of two general types: those that produce wounds, and those that inflict stings.

Sharks

(2) Among the marine animals that produce wounds, sharks are generally the most feared. There are more than 225 species of sharks, but only a score or more are believed to attack men. Information concerning the more important of these species is summarized in tables E-1 and E-2, and the more readily recognized species are pictured in figures E-1 and E-2.

(3) It is difficult to make specific statements concerning the actual risk of attacks by sharks. As a whole, the experience of divers indicates that the risk is almost negligible, but the possibility of attack does exist. A number of general statements about the problem can be made:

(*a*) The danger of shark attacks is greatest in tropical and subtropical seas, between 30° north and 30° south of the Equator. Particularly dangerous areas are Queensland, Australia, and South Africa. Most attacks have occurred when the temperature of the water was greater than 70° F. The peak month of attacks in tropical waters is January, and the time of greatest risk is between 1500 and 1600 hours. However, sharks feed at all hours, and particularly at night.

(*b*) Sharks are attracted by blood, carrion, flashing lights, colored materials, thrashing about, explosions, or unusual noises. When they are hunting in packs and food or blood is present, sharks become highly excited and may radi-

TABLE E-1.—*Marine life, sharks*

Name	Danger[1]	Maximum size, foot	Appearance[2]	Behavior	Where found
White shark	4+	30	Slate-brown to black on back.	Savage, aggressive	Oceanic, tropical, subtropical, warm temperate belts, especially in Australian waters.
Mako shark	4+	30	Slender form, deep blue-gray on back.	Savage	Oceanic, tropical, and warm temperate belts.
Porbeagle shark	2+	12	Dark bluish-gray on back.	Sluggish except when pursuing prey.	Continental waters of northern Atlantic. Allied forms in North Pacific, Australia, and New Zealand.
Tiger shark	2+	30	Short snout, sharply pointed tail.	Can be vigorous and powerful.	Tropical and subtropical belts of all oceans, inshore and offshore.

See footnotes at end of table.

TABLE E–1.—*Marine life, sharks*—Continued

Name	Danger [1]	Maximum size, foot	Appearance [2]	Behavior	Where found
Lemon shark	2+	11	Yellowish-brown on back, broadly rounded snout.	Found in salt-water creeks, bays, and sounds.	Inshore western Atlantic, northern Brazil to North Carolina, tropical West Africa.
Lake Nicaragua sharks.	2+	10	Dark gray on back	Found in shallow water.	Fresh-water species of Lake Nicaragua.
Dusky shark	1+	14	Bluish- or leaden-gray on back.	Found in shallow water.	Tropical and warm, temperate waters on both sides of Atlantic.
White-tipped shark.	3+	13	Light gray to slate-blue on back.	Indifferent, fearless	Tropical and subtropical Atlantic and Mediterranean. Deep offshore waters.
Sand shark	2+	10	Bright gray-brown on back.	Stays close to bottom	Indo-Pacific Mediterranean, tropical West Africa, South Africa, Gulf of Maine to Florida, Brazil, Argentina.
Gray nurse shark	3+	10	Pale gray on back	Swift and savage	Australia.
Ganges River shark.	4+	7	Gray on back	Ferocious, attacks bathers.	Indian Ocean to Japan, ascends fresh water rivers.
Hammerhead shark.	4+	15	Ashy-gray on back; flat, wide head.	Powerful swimmers	Warm temperate zone of all oceans including Mediterranean Sea, out at sea or close inshore.

[1] 1+ means minimum danger; 4+ means maximum danger.
[2] All sharks listed are some shade of white on undersides.

TABLE E–2.—*Marine life, other forms*

Name	Danger	Maximum size	Appearance	Behavior	Where found
Great barracuda	4+	6–8 ft	Long and slender; large mouth.	Swift, fierce, easily attracted.	Tropical and subtropical waters, West Indies, Brazil, northern Florida; in the Indo-Pacific from Red Sea to Hawaiian Islands.
Groupers	2+	12 ft; 700 lb	Bulky type of body	Curious and bold; voracious feeders.	Around rocks, caverns, old wrecks.
Moray eels	1+	10 ft	Long, narrow, snakelike.	Attack when provoked.	Tropical and subtropical bottom dwellers.

TABLE E–2.—*Marine life, other forms*—Continued

Name	Danger	Maximum size	Appearance	Behavior	Where found
Killer whales	4+		Jetblack head and back, white underparts.	Ruthless, ferocious	All oceans and seas, tropical to polar. *Caution:* Leave water immediately if sighted.
Sea lions	1+		Resemble seals but are larger.	Curious; fast swimmers.	Northern waters.
Sea urchins	2+		Small spiny animals	Needle-sharp spines, small venomous pincers.	Tropical and temperate zones, ocean floor on rocks and coral reefs.
Corals	1+			Extremely sharp	Tropical and subtropical waters.
Barnacles, mussels.	1+			Inflict deep cuts	Rocks, pilings, wrecks.
Giant clams	2+	Several hundred pounds.		Trap legs and arms of victim between shells.	Abound in tropical waters.
Portuguese man-of-war.	3+	6-in. diameter	Tentacles up to 50 feet long.	Stings with cells on tentacles.	Tropical waters.
Sea wasp	4+		Tentacles up to 50 feet long.	Stings with cells on tentacles.	Northern Australia, Philippines, Indian Ocean.
Octopuses	2+	25 ft	Arms radiating from head.	Hold with tentacles; also bite.	Underwater caves.
Cone shells	2+		Colorful shells	Penetrate skin with venom-filled teeth on proboscis (trunk).	Widespread.
Horned sharks	1+		Spines anterior to back fins.		
Stingrays	1+	Several feet	Spine on top of tail, flat body.	Drive spine into leg when stepped on.	Tropical to temperate waters.
Catfish	1+		Venomous dorsal and pectoral spines.		Tropical and temperate, mostly fresh water, some marine.
Weeverfish	1+		Venomous dorsal and pectoral spines.	Toxic to the nervous system and blood, extremely painful.	Eastern Atlantic and Mediterranean.
Scorpionfish	1+		Venomous back, anal, and pelvic spines.	Toxic to the nervous system and blood.	Tropical and temperate.
Sea snakes	3+	9 ft	Resemble snakes; venomous fangs.	Boldness varies	Tropical Pacific and Indian Ocean River mouths to far at sea.

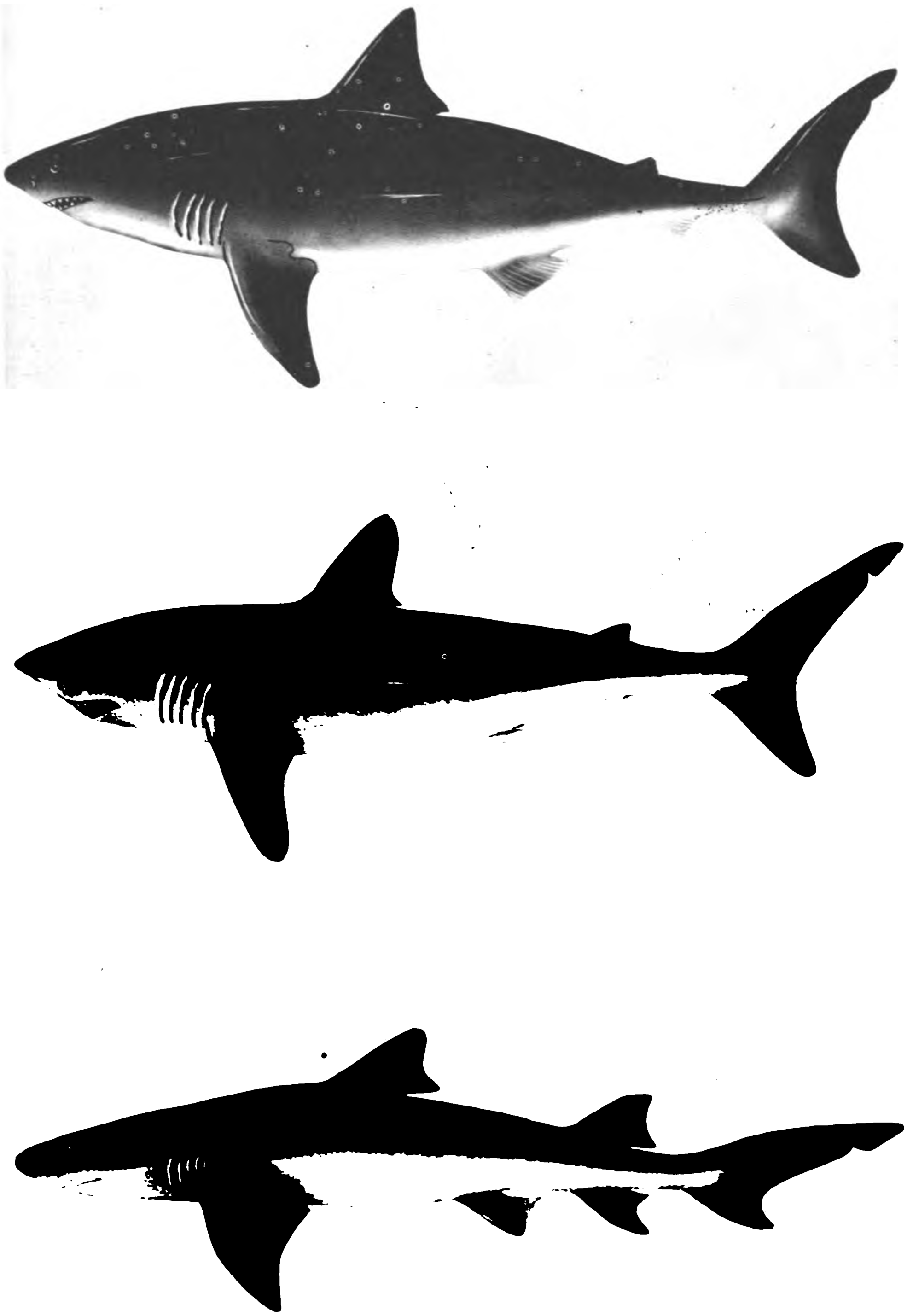


FIGURE E-1.—White shark, mako shark, tiger shark.

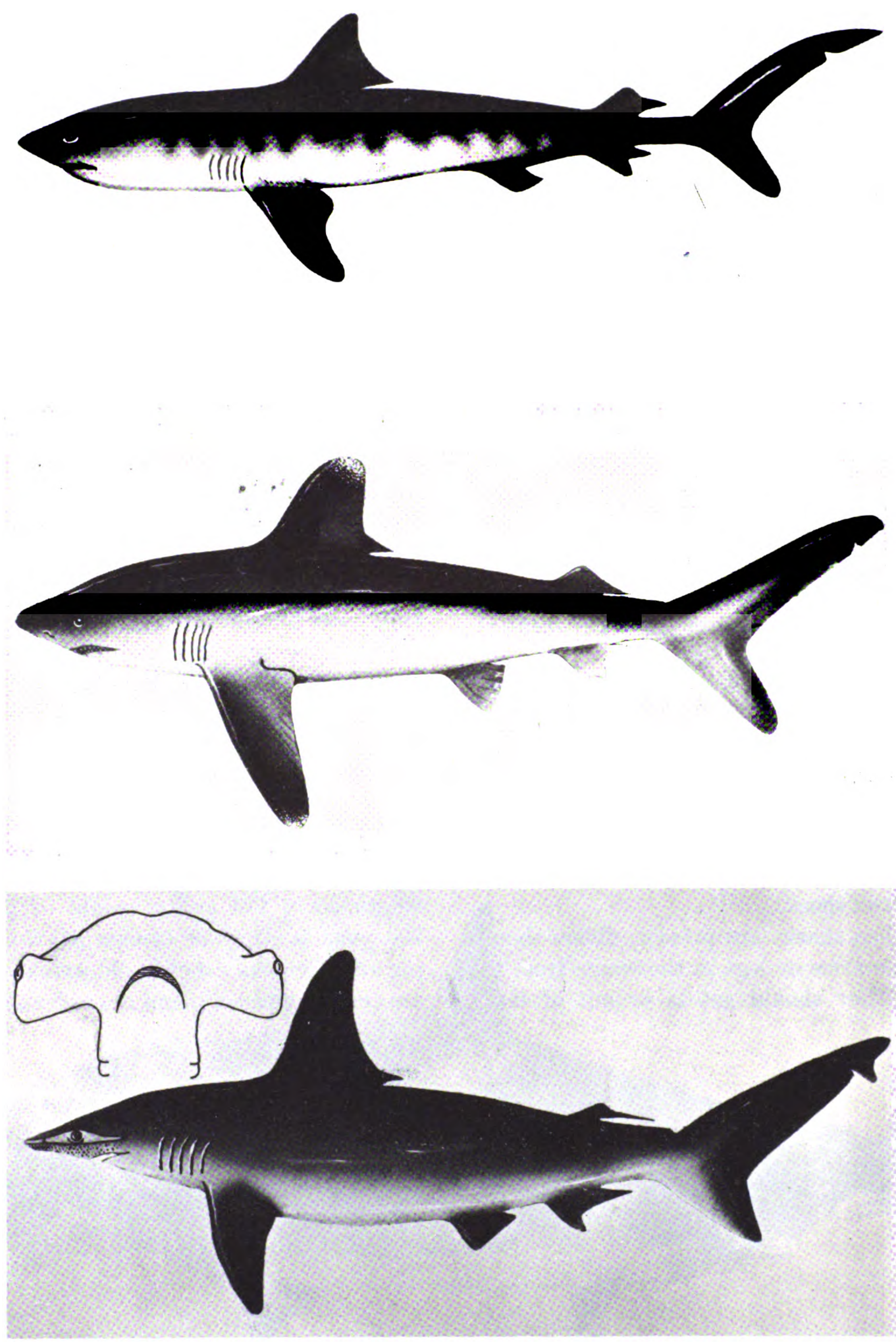


FIGURE E-2.—Lemon shark, white-tipped shark, hammerhead shark.

cally alter their usual habits. It is at such times that the greatest danger is encountered, and shark repellants are useless in such situations. Sharks will frequently single out an individual in a crowd and will ignore others who may attempt to rescue him. Several men together, however, are in a better position to ward off sharks than is a lone swimmer.

(*c*) Various suggested methods of chasing sharks away—by banging rocks together, blow ing bubbles, shouting, splashing, and such—are of questionable value when the shark is highly excited. These actions may even attract the shark. Movement should be slow and purposeful. It has been demonstrated that if an individual is not wounded, the sharks may leave the area if he remains perfectly still. It may be necessary actually to shove the shark away with the use of a shark billy—a large stick that is carried for this purpose—or some other object. Attempts to wound the shark are usually useless and may even aggravate the situation; but if such action appears necessary, hit the shark on the snout, eyes, or gills.

(*d*) In general, dark-colored clothing and equipment are preferable to light-colored articles. The use of explosives can usually be expected to attract sharks in large numbers.

(*e*) The fatality rate from actual shark attacks has been estimated at more than 80 percent. Bites are severe, and death is due to massive bleeding and shock.

(*f*) When sharks are present, divers should not dangle arms or legs in the water from the surface. They should get in or out of boats quickly. An injured swimmer should not remain in the water.

Barracuda

(4) There are about 20 species of barracuda. The great barracuda (fig. E–3) is one of the most dangerous. It is widely distributed throughout the tropical and subtropical waters of the world. The great barracuda is found in the West Indies and Brazil, north to Florida, and in the Indo-Pacific from the Red Sea to the Hawaiian Islands.

(*a*) Great barracuda can attain a length of 6 to 8 feet. They have large mouths filled with enormous knifelike canine teeth, are swift swimmers and strike rapidly and fiercely. In some areas they are more feared than sharks. They are attracted by anything which enters the water, particularly colored objects. They will follow divers by the hour, but have seldom been known to attack.

(*b*) Barracuda wounds can be differentiated from those of a shark because barracuda wounds are straight cuts, whereas shark wounds are curved like the shape of their jaws. The barracuda will strike at any speared fish that a diver may be carrying. Barracuda should be treated with respect.

Groupers

(5) Some of the giant groupers attain a length of 12 feet and a weight of more than 700 pounds. They are frequently found lurking around rocks, caverns, old wrecks, etc. They are curious and bold, and are ravenous feeders.

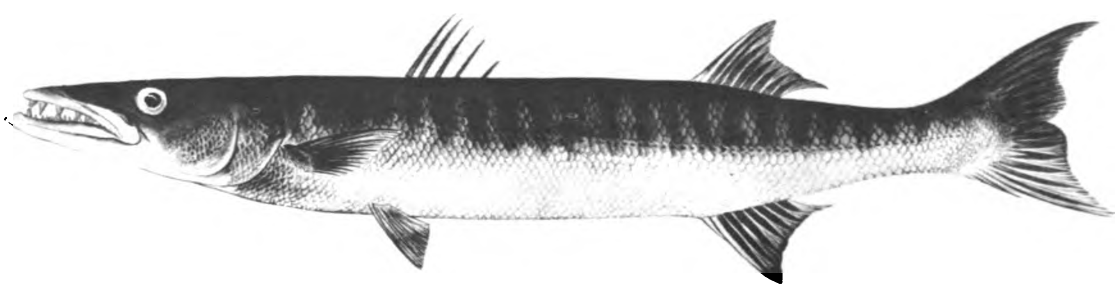


FIGURE E–3.—Great barracuda.

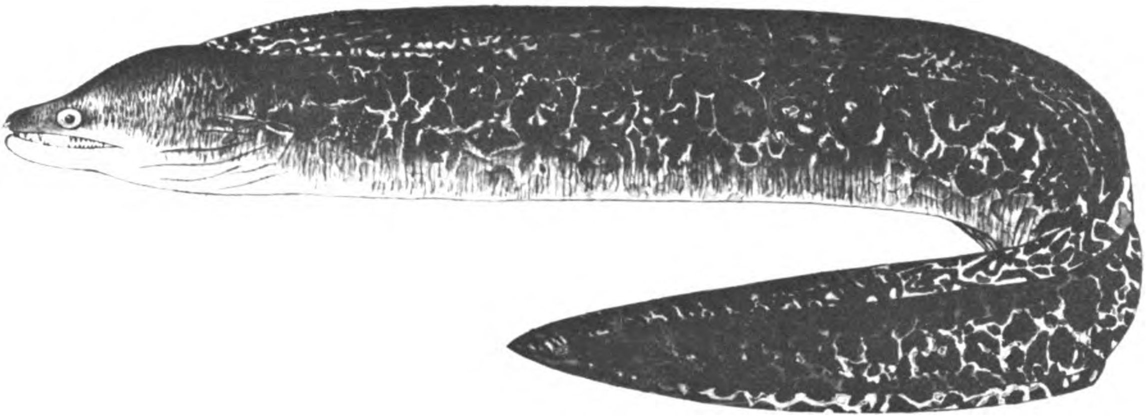


FIGURE E-4.—Moray eel.

Their feeding characteristics coupled with their large size make them a potential danger to the skindiver. Several fatal attacks have been reported.

Moray Eels

(6) Moray eels (fig. E-4) are seldom found except in tropical and subtropical seas. They can attain a length of 10 feet. Morays are bottom dwellers, and are commonly found lurking in holes and writhing through crevices under rocks and corals. They seldom attack unless provoked, but provoking them is not difficult. When encroaching upon their habitat by reaching into dark holes and crevices, one should move with great caution. The moray's narrow jaws are armed with strong knifelike or crushing teeth which can inflict severe lacerations. The jaws frequently maintain their grip until the moray eel itself is dead.

Killer Whales

(7) The killer whale (fig. E-5) has the reputation of being a ruthless and ferocious beast. It is found in all oceans and seas, tropical and polar alike. The killer whale is characterized by a bluntly rounded snout, a high, black top

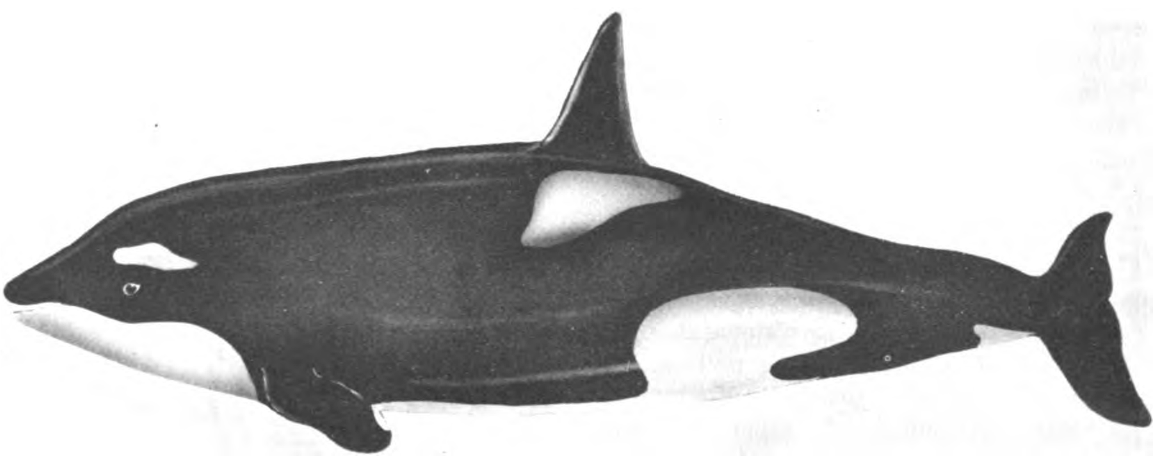


FIGURE E-5.—Killer whale.

fin, a white patch just behind and above the eye, and the striking contrast of the black color of the head and back with the white underparts. Killer whales hunt in packs of 3 to 40 individuals, preying on other warmblooded marine animals. They are fast swimmers, will attack anything that swims, and have been known to come up under ice flows to knock seals and people into the water. If a killer whale is seen in the area, the diver should leave the water immediately.

Sea Lions

(8) Sea lions are fast swimmers, and they are curious. They have been known to nip at skindivers. The diver should keep away from sea lions, especially during breeding time or when young sea lions are in the water.

Barnacles and Mussels

(9) Certain shellfish, such as barnacles and mussels, that grow on rocks, pilings, wrecks, and the like, are sharp and can cause deep cuts if a diver is forced against them.

Giant Clams

(10) Tridachma, or the so-called giant or killer clams, abound in tropical waters. Some of them attain huge proportions and can weigh several hundred pounds. Although accidents from them are rare, one should learn to recognize them and avoid catching a foot or hand between the two valves. Drownings have occurred from divers accidentally stepping into the open shells and becoming trapped. In order to release the victim, a knife must be inserted between the shells to sever the clam's adductor muscle.

Animals That Inject Venom

(11) Venomous marine animals are for the most part slow moving or tend to remain in one spot. In some instances, as with stonefish, scorpionfish, and stingrays, they are well camouflaged and exceedingly difficult to distinguish from their surroundings. In other instances, they are spectacularly colored and attract attention, as in the case of zebrafish and some jellyfish. Colors typical of many venomous creatures are combinations of black and orange.

Jellyfish

(12) Forms of marine life commonly included under the term "jellyfish" are found in large numbers in all oceans, in bays, and in the tidal portions of rivers. At times, they concentrate to such a degree that contact with a swimmer is almost inevitable.

(*a*) Of the stings of the most dangerous types, the Portuguese man-of-war (see E–6(*a*)) and the sea wasp (see E–6(*b*)) can have extremely serious effects. Both of these organisms are rather small in size, seldom exceeding 6 inches in diameter at the central portion. The

FIGURE E–6(*a*).—Portuguese man-of-war.

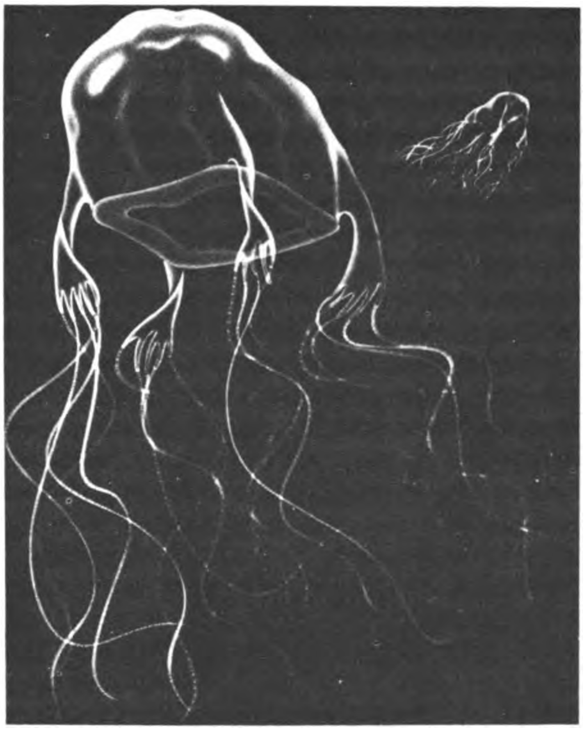


FIGURE E-6(b).—Sea wasp.

tentacles may reach a length of 50 feet. The Portuguese man-of-war is largely an inhabitant of tropical waters. The sea wasp is found in the waters about northern Australia and the Philippines and in the Indian Ocean. The sea wasp is considered the most dangerous type.

(b) The method of stinging is found in a series of specialized cells located largely on the tentacles. Contact with these cells sets off a triggerlike mechanism which ejects a tiny thread tube from a venom-filled cell. Many thousands of these microscopic cells are to be found on the tentacles of a single jellyfish.

(c) The symptoms of jellyfish stings vary according to the species of jellyfish, the extent and duration of contact, the site of the sting, and the health of the victim. Symptoms vary from mild but immediate prickly or stinging sensation, like that of a nettle sting, to an intense burning, throbbing, or shooting pain which may render the victim unconscious. The area coming in contact with the tentacles usually becomes red, followed by the appearance of welts (puffy patches of skin), blisters, swelling, and small skin hemorrhages. In severe cases, in addition to shock, there may be muscular cramps, abdominal rigidity, loss of the senses of touch and temperature, nausea, vomiting, severe backache, loss of speech, frothing at the mouth, sensation of constriction of the throat, respiratory difficulty, paralysis, delirium, convulsions, and death. The sea wasp sting has been known to kill a man within 5 minutes or less.

(d) If the diver is stung, he should call for help at once and get out of the water as soon as possible. Someone should seek medical assistance while the following treatment is administered:

1. Remove tentacles and as much of the stinging fluid as possible. (Protect hands by using a cloth, a stick, seaweed, or a handful of sand; try to avoid spreading the material.) Apply weak ammonia or saturated sodium bicarbonate (baking soda) solution if available. Otherwise, rub area gently with wet sand. Then wash area with fresh water.

2. Attempt to reduce local reaction. Use cortisone ointment, antihistamine cream, or local anesthetic ointment if available. Otherwise, try olive oil, sugar, soothing lotions, or ethyl alcohol. Apply cold compresses.

3. Try to check general reaction and shock. Keep victim lying down; elevate feet. Give artificial respiration if needed. Give oral antihistamine preparation if victim is conscious (see app. A).

4. Medical personnel may use the following if considered necessary: epinephrine for "allergic shock," adrenocortical preparations for local and general reaction, morphine for pain (unless respiration is depressed), careful intravenous injection of calcium gluconate for muscular cramps, and respiratory and cardiac stimulants. Intravenous fluids should be administered for shock. (Note that there is no specific antidote.)

(e) To prevent jellyfish stings:

1. Be alert to avoid contact when possible.

2. Wear well-fitting underwear or a rubber suit, especially for night operations or when jellyfish are thickly congregated.

3. Remember that tentacles of some forms stream considerable distances from the central portion and that stings can be inflicted even by detached and broken tentacles of seemingly dead jellyfish washed up on the beach.

Corals

(13) Divers who must work about reefs frequently sustain cuts and abrasions from contact with coral formations. The injuries are generally superficial, but they are usually very slow in healing and can cause loss of much operational manpower. Although some forms of coral inflict only a dirty wound, others produce additional injury and reaction by means of stinging cells similar to those of jellyfish.

(*a*) Even without the stinging effect, a coral wound can be unusually painful and troublesome. Especially under unfavorable living conditions, even a simple scratch left untreated can become a pus-forming ulcer surrounded by a painful reddened area. The initial effect of a coral sting or coral poisoning is a violent reaction with pain and itching sensations in and around the wound accompanied by reddening and welt formation in the surrounding skin area. Severe general reactions, like those seen with some jellyfish stings, are not frequent.

(*b*) Treat the wound as follows:

1. Rinse area with baking soda solution or weak ammonia if available. Otherwise, rinse with clean water.

2. Use cortisone ointment or antihistamine cream on the wound and give antihistamine by mouth to help reduce initial pain and reaction.

3. As soon as pain begins to subside, cleanse wound thoroughly with soap and water to remove all foreign material. Apply an antiseptic and cover wound with a sterile dressing.

4. In a severe case, give patient bedrest, with elevation of the affected limb. Apply kaolin poultices or wet dressings of magnesium sulfate solution in glycerine (see app. A).

(*c*) To prevent injuries from coral, wear gloves, shoes, and other appropriate protective gear when working around coral.

Octopus

(14) Although large specimens of octopus may exceed 25 feet in span, those found at the usual diving depths are generally much smaller. They tend to be inquisitive rather than vicious (see fig. E–7).

(*a*) One possible danger of contact with an octopus lies in the fact that even a relatively small one might trap a diver underwater if it could get a good grip on the diver and a rock at the same time. Clothing such as wool underwear will hinder attachment of the suction cups. Because underwater caves, crevices, and wrecks are favorite haunts of the octopus, these are best avoided when possible.

FIGURE E–7.—Octopus.

(*b*) The octopus has a well-developed venom apparatus associated with its beak and can produce injurious effects by biting. Symptoms of a bite include a stinging sensation with swelling, redness, and heat in the area about the wound. Death has also been reported. There is no specific treatment (see app. A).

(*c*) Stabbing the octopus deep between the eyes is the best method of killing an octopus.

Cone Shells

(15) Cone shells are shell collectors' favorite items because of their attractive patterns. There are more than 400 species of cone shells and all of them contain a highly developed venom apparatus. Several of the tropical species have caused human deaths. The living shell contains a sluglike animal that can crawl out. If the animal is disturbed, microscopic venom-filled teeth may be suddenly moved from the inside of the animal to the proboscis (trunk) where they can be utilized as a stinging apparatus. The diver

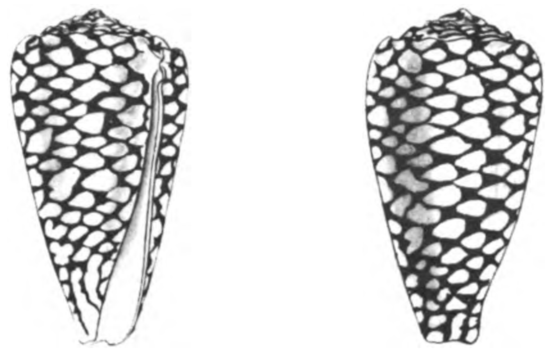


FIGURE E-8.—Cone shell.

should avoid coming in contact with the soft parts of the animal (see fig. E-8).

(*a*) The stings are of the puncture variety. Localized ischemia (shutting down of blood supply), cyanosis (blueness), or a sharp stinging or burning sensation are usually the initial symptoms. Numbness and paresthesias (abnormal sensations) begin at the wound site and may spread rapidly, involving the entire body, particularly about the lips and mouth. In severe cases paralysis may follow. Respiratory distress is usually absent. Coma may ensue and death is said to result from heart failure.

(*b*) There is no specific treatment. Cases of cone shell stings should be treated like venomous fish stings (see app. A).

Sea Urchins

(16) Sea urchins (see fig. E-9) exist in numerous species and vary in characteristics such as length and shape of the spines. In most cases, the spines are solid and have blunt, rounded tips which do not inject venom. A few have long, slender, hollow spines that are sharp and dangerous. The sharp tips permit easy penetration, but small barbs and extreme brittleness cause the spines to break off when removal is attempted. Some sea urchins also have small,

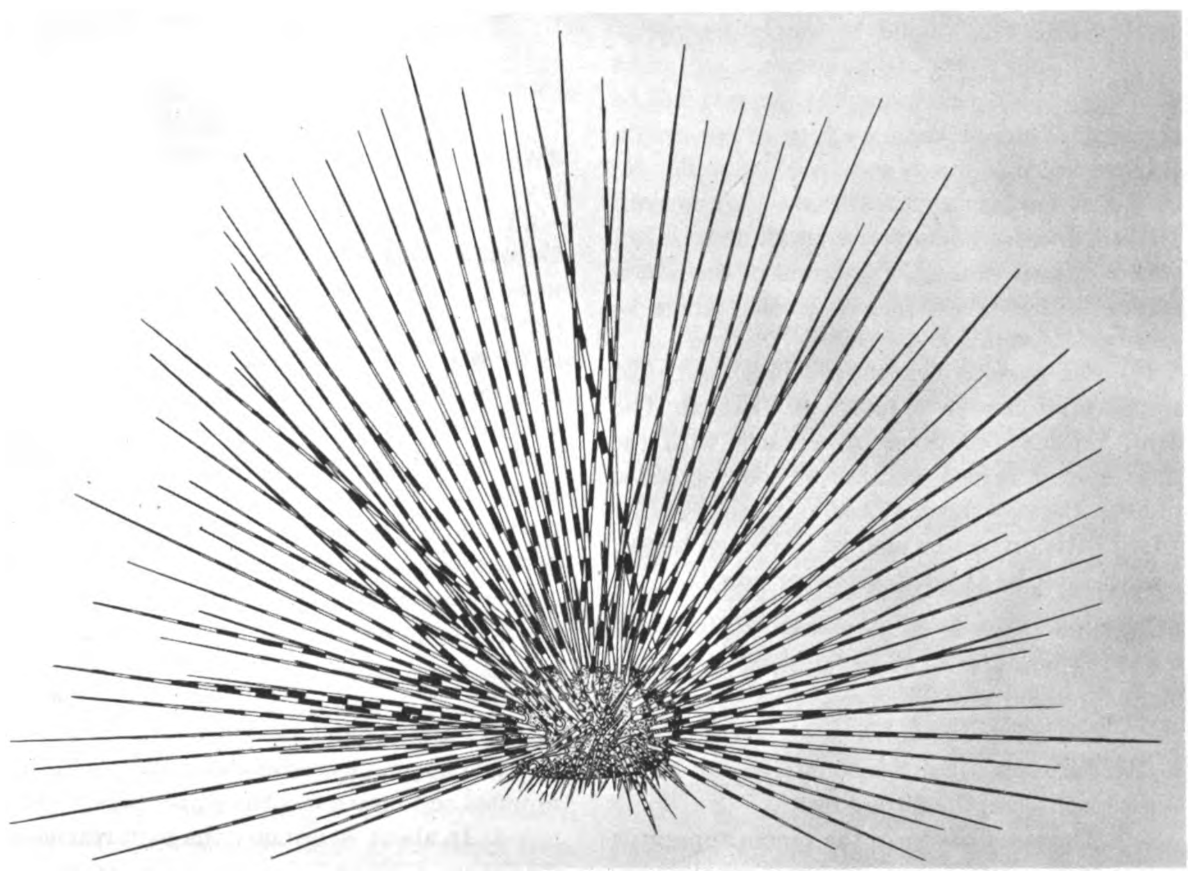


FIGURE E-9.—Sea urchin.

venom-carrying pincers. These are generally spread over the surface of the shell and may appear buried near the base of the spines. They are on stalks and can be extended. The pincers consist of sharp, stonelike jaws enclosed within a venom gland.

(*a*) Penetration with the spines may result in an immediate and intense burning sensation, followed by redness, swelling, and aching. Weakness of the legs, anesthesia (loss of body sensation) swelling of the face, and irregularities in the pulse have been noted. Secondary infection may result. Severe cases may produce an intense radiating pain, faintness, numbness, generalized paralysis, loss of voice, respiratory distress, and even death.

(*b*) When sea urchin spines are broken off in the skin, as many spines as possible should be removed with forceps. The area should then be cleansed and cushioned with a large, loose dressing. If any evidence of infection appears, medical attention should be sought promptly. Spines of some types will be absorbed within 24 to 48 hours; otherwise, surgical removal will be required. When a venomous type of sea urchin is involved, the pincers should be promptly removed from the wound because they remain active for several hours and continue to inject venom into the wound. Treatment of the case is otherwise like that for venomous stings in general (see app. A).

(*c*) Sea urchins that have long, needlelike spines must not be touched or handled. The diver must be cautious in contacts with the short-spined variety because of the venomous pincers. Because shoes, gloves, suits, and the like afford little protection against the sharp spines, contact must be avoided whenever possible.

Stingrays

(17) There are many varieties of rays, and many of them are venomous. One example is the round stingray which is shown in figure E–10. Varieties usually encountered can sometimes reach a length of 3 or 4 feet.

(*a*) The exact nature of the venom apparatus varies from species to species, but it usually consists of a spine covered by a skinlike sheath. The spine is located on the upper side of the tail at a variable distance from the base of the tail.

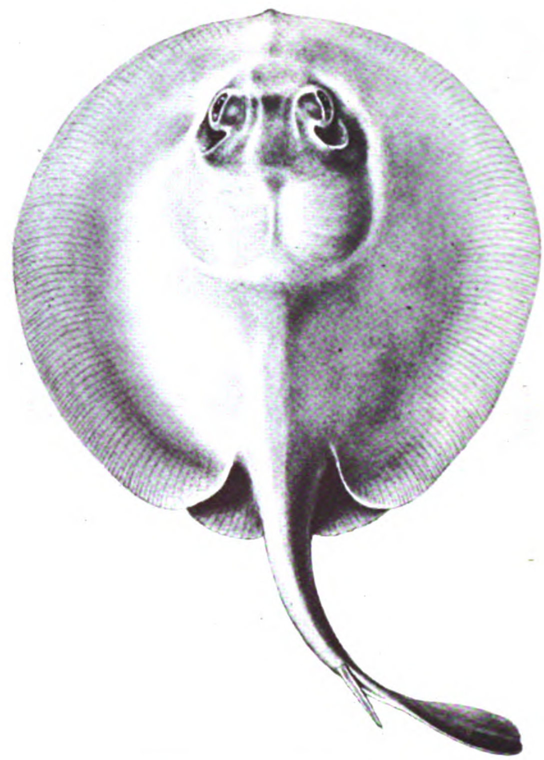


FIGURE E–10.—Round stingray.

(*b*) Stingrays are generally found lying on the ocean bottom in shallow water. They are usually well camouflaged and are often partly covered by sand. The main danger to a swimmer or diver is that of stepping on a stingray. When stepped on, the ray strikes upward with its tail and drives the spine deeply into the foot or leg. This usually produces a ragged, dirty wound. Often all or part of the sheath of the spine remains in the wound. The venom produces severe pain, and if present in large quantities it can cause generalized effects.

(*c*) Symptoms:

1. Local pain develops within 4 to 10 minutes.

2. Fainting and weakness are common.

3. The pain increases in intensity within 30 minutes and may affect the entire lower leg.

4. In about 90 minutes the pain reaches its maximum intensity, is extremely severe, and may involve the whole limb.

(*d*) Recognition of a stingray wound is aided by these observations:

1. A puncture or lacerated wound found on the upper portion of the foot or ankle. (Victim may recall that he stepped on something soft and slippery.)

2. Pain within a few minutes, increasing in intensity, and finally affecting the entire limb.

3. Shock symptoms with fainting, nausea. and weakness.

4. Muscular spasms of the affected limb.

(*e*) Because fainting is common, victim must be gotten out of the water promptly. Treatment must be started at once:

1. Wash wound with sterile saline solution if this is available; otherwise wash with cold, clean water.

2. Try to remove any remaining portions of the stinger sheath.

3. Soak in plain water, as hot as can be tolerated, for at least 30 minutes. Use hot compresses on areas that cannot be immersed (see app. A). (Heat is believed to destroy the venom.)

4. If pain is severe and fails to respond to heat treatment, local injection of 0.5 to 2 percent procaine can be tried. If local measures fail to relieve pain, intramuscular or intravenous Demerol is usually effective.

5. When pain has subsided, cover the wound and elevate the limb.

6. Obtain medical assistance for further treatment of the wound. (Most wounds can be sutured if treated early and properly. If the wound is large, a drain should be left in place for a day or two.)

7. Give a booster injection of tetanus toxoid.

8. Use antibiotics if signs of infection appear.

(*f*) Special considerations.

1. If the victim is wounded in the chest or abdomen, get him to a hospital at once.

2. If signs of shock (fainting, weak pulse, falling blood pressure) appear, keep victim lying down, and obtain medical help immediately. (Treatment is the same as for shock from other causes, with special emphasis on maintaining cardiovascular tone.) (See app. A.)

Venomous Fishes

(18) Fishes that inflict poisonous stings are found throughout the world, but are most common in tropical waters. They tend to be quiet in their habits. Injury is produced by contact with poison-bearing spines. A diver should learn to recognize the most important venomous fish groups mentioned here. (Symptoms and treatment of stings from these species are discussed in (22) below.)

(*a*) *Horned sharks.*—These include bullhead sharks, the spiny dogfish, and some less common species. The venom organs consist of two spines, one in front of each back fin.

(*b*) *Catfish.*—These fish are largely found in fresh water. Their venom apparatus consists of spines on the back and behind the gills. The venom is believed to have effects on the nerves and the blood.

(*c*) *Weeverfish.*—These fish are small and found only along the eastern Atlantic and Mediterranean coasts (see fig. E–11). They have poison-bearing spines on the back and head. The venom is powerful and resembles that of certain snakes. It affects both nerves and blood. The stings are extremely painful.

(*d*) *Scorpionfish.*—Poisonous scorpionfish can be found in all tropical and temperate seas. The most dangerous species under this classification are—

1. Scorpionfish, proper (see fig. E–11).

2. Zebrafish (see fig. E–11).

3. Stonefish (see fig. E–11).

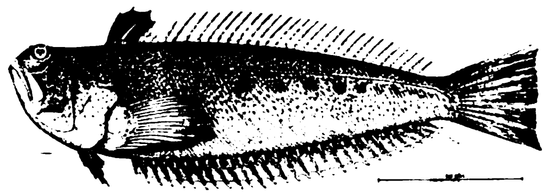
4. Tropical scorpionfish.

Most of these carry venomous spines on the back and about the tail. The venom resembles that of the weeverfish.

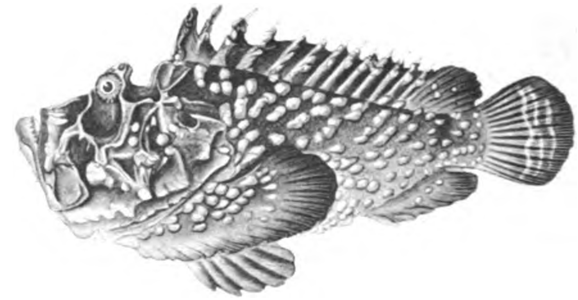
(*e*) *Other venomous fish.*—Numerous other kinds of fish are capable of inflicting stings. In many cases, rather little is known about them. Several fish deserving to be mentioned and the areas where they may be found are—

1. *Ratfish.*—One type is found in European waters; another along the Pacific coast of North America. They carry a single spine on the back.

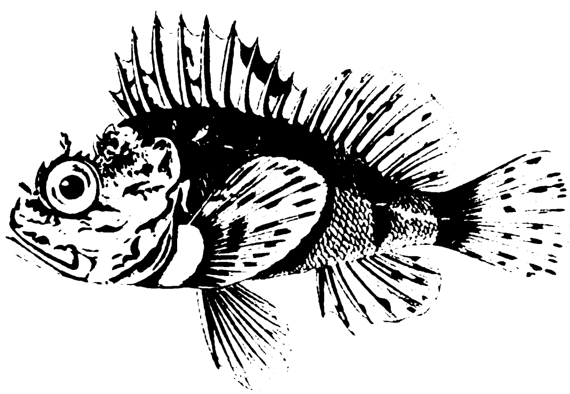
2. *Toadfish.*—These are found in the warmer waters along the coasts of America, Europe, Africa, and India. They have hollow spines on the back and head.



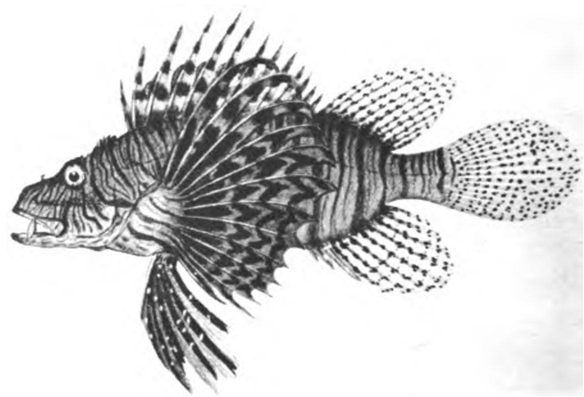
Weeverfish



Stonefish



Scorpionfish



Zebrafish

FIGURE E-11.—Venomous fishes.

3. Surgeonfish.—These are found along reefs in warm seas. They have a sharp, lance-like movable spine near the tail.

4. Rabbitfish.—These abound about rocks and reefs from the Red Sea to Polynesia. Their venom apparatus includes spines on the back, belly, and near the tail.

(*f*) *General comment.*—When diving in an unfamiliar area, it is wise to consult local divers or appropriate authorities for information conerning particular marine-life hazards of the region. This is particularly true of venomous fish, as they present a particularly difficult problem in recognition.

(19) The effects of venomous fish stings vary with the species, the extent of contact, and other factors. In general, they resemble those of stingray injury, although most produce less sizable wounds and some produce more serious local and general reactions. Some of the effects are similar to those of snakebite. Pain results from the actual injury produced by the spine, from the effects of the venom, from the irritation of slime, and from other foreign substances introduced into the wound.

(20) The victim should be got out of the water as soon as possible because of the probability of fainting and serious general reactions. The victim should be kept lying down and the rescuer should watch for signs of shock. Medical assistance must be secured.

(*a*) Proceed with the measures indicated for stingray injuries (see (19)(*e*)), with this exception: If the injury is of the small, puncture-wound type, make a small incision at the site to encourage bleeding and to make flushing possible. Flush with sterile saline or clean, cold water. Remove any visible foreign material. Use suction if a method of applying it without using the mouth is available.

(*b*) Some authorities recommend the following treatment for stings of the hand or foot:

1. Immediately after being stung, place a tourniquet between the site of the sting and the rest of the body at the closest possible point to the injury.

2. Immerse the hand or foot, including the tourniquet, in iced fresh water. (Iced sea water will produce a dangerously low temperature.)

3. After not less than 5 minutes nor more than 10 minutes of soaking in the ice water, remove the tourniquet.

4. Keep the part in ice water for not less than 2 hours.

5. Carry out other necessary measures including treatment for shock, later care of the wound, and the like (see app. A).

Sea Snakes (see fig. E–12)

(21) In general appearance, sea snakes resemble the land varieties. Coloration varies considerably among about 50 species. They rarely exceed 3 or 4 feet in length, but a few species may attain a length of 9 feet or more. The body is compressed at the rear to form a paddle-shaped tail. The forward part of the upper jaw carries one or two hollow, venom-injecting fangs on each side. These resemble the fangs of a cobra but are smaller.

(*a*) Sea snakes remain in the water all the time. Only one species lives in fresh water. They are found mainly in the tropical Indian and Pacific Oceans, and most of the species prefer sheltered coastal waters and river mouths. Sea snakes have been seen swimming together or breaking the surface in large numbers. They are able to float on the surface for long periods of time, and although they are air breathers, they can remain submerged for long periods of time.

(*b*) Although unprovoked attacks are very rare, the species vary in disposition. Because the venom is extremely potent, all sea snakes should be carefully avoided.

(22) Sea-snake bites are unusual in that there is a considerable delay between the injection of venom and the reaction. (The delay varies from 20 minutes to several hours. The average is about 1 hour.) Also, there is no pain or reaction at the site. Some victims fail to realize the connection between the bite and the illness.

(*a*) The beginning symptoms usually include the following:

1. A general ill feeling and anxiety in some cases, a mild euphoria (false sense of well-being) in others.

2. A sensation of thickening of the tongue.

3. A generalized feeling of muscular stiffness.

4. Aching, or pain on movement.

(*b*) Somewhat later symptoms include—

1. Weakness that progresses to actual inability to move, including the whole body within an hour or two, beginning with the legs and moving upward. (This paralysis is usually of the flaccid, or flexible, type, but the spastic, or rigid, form is sometimes seen.)

2. Drooping eyelids.

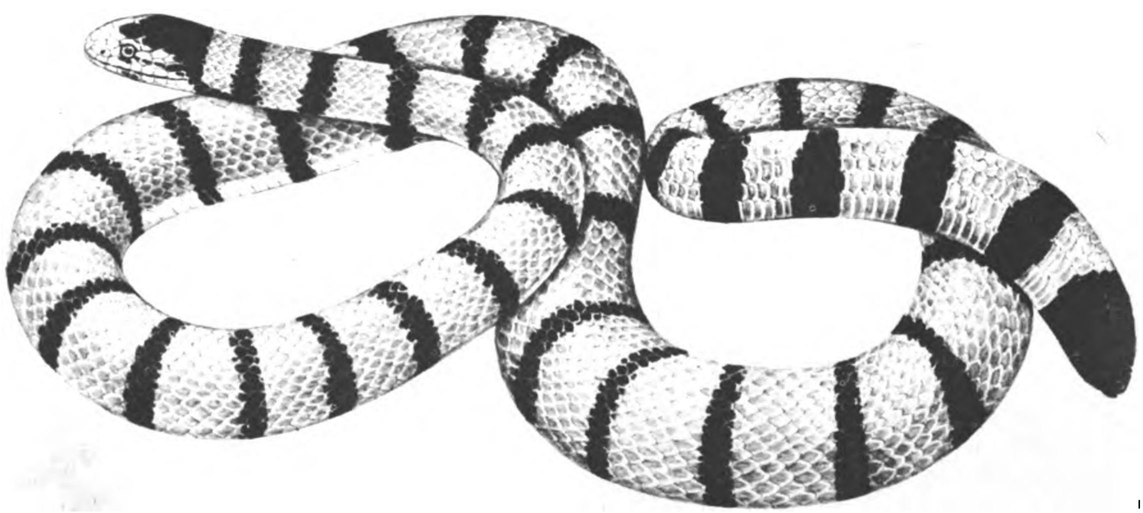


FIGURE E–12.—Sea snake.

3. Tightening of the jaw muscles, not unlike that seen in tetanus (lockjaw).

4. Increasing difficulty speaking and swallowing.

5. Thirst, burning, or dryness of the throat.

(*c*) Shock very frequently develops. Symptoms that may also occur include—

1. Muscular spasms.

2. Paralysis of face and eye muscles.

3. Respiratory difficulty.

4. Convulsions.

5. Unconsciousness.

(*d*) Death occurs in an average of about 25 percent of cases of sea-snake bite. The final cause of death varies, but shock, respiratory difficulty, and convulsions are probably most often responsible. If recovery occurs, it is complete. Late effects do not occur.

(23) Diagnosis of sea-snake bite can be difficult, especially if the bite was slight and if the victim did not see the snake. Prompt diagnosis is important because of the treatment required. The following points can be helpful in distinguishing it from other types of marine-life injury:

(*a*) Victim has usually been in the water or working with nets or other equipment in a coastal area or near a river mouth.

(*b*) Pain is absent after the initial prick.

(*c*) Fang marks (two circular dots or two pairs of dots half an inch or so apart) should be visible at the site of pain. There is no swelling, bruise, bleeding, or tenderness in the area. (Sometimes a fang will be found embedded in the skin.)

(*d*) Symptoms generally develop as discussed previously.

(24) Treatment: Immediate steps should include the following:

(*a*) Keep the affected part quiet; avoid exertion.

(*b*) If bitten on a leg or arm, apply a tourniquet above the bite. Release it every 30 minutes for 5 minutes.

(*c*) Get help promptly.

(*d*) Transport victim quietly to the nearest medical facility. (Medical assistance is essential, and hospitalization should be provided if at all possible.)

(*e*) If possible, capture and kill the snake and have it identified. (It may prove to be a harmless type.)

(*f*) Give antivenin treatment at the earliest possible moment.

1. Give cortisone first to prevent serum reaction. Have epinephrine ready in case a reaction occurs.

2. Use a polyvalent antiserum containing a Krait (*Elapidae*) fraction. (There is no serum specifically made for sea-snake bits.)

3. Give 20 milliliters of antiserum by slow, cautious, intravenous injection.

4. Be prepared to give additional amounts of antiserum if required.

(*g*) Recovery of the patient may depend on a great many factors. Medical personnel should keep the following in mind:

1. Take all necessary steps to prevent or treat shock.

2. Provide constant reassurance to the patient.

3. Maintain fluid intake and electrolyte balance.

4. Watch for respiratory difficulty or inadequacy. Treat as a case of bulbar poliomyelitis or tetanus if necessary.

5. Provide sedation and anticonvulsant therapy if needed. Avoid morphine because of respiratory depression (see app. A).

6. Use antibiotics in the event of wound infection or pneumonia.

(25) If working near coasts and river mouths, around rocky crevices, piers, old tree roots, and other places likely to be inhabited by sea snakes, be aware of the danger. If snakes are seen, avoid them carefully.

U.S. NAVY DIVING MANUAL

APPENDIX F

SELECTION, QUALIFICATION, AND TRAINING OF PERSONNEL

370-711 O - 70 - (Faces page 652)

CONTENTS

F–A. GENERAL

(1) In the selection of personnel for diving training, the commanding officers and examining boards shall be guided strictly by the Bureau of Naval Personnel Manual, the Manual of the Medical Department, Catalog of U.S. Naval Training Activities and Courses (NAVPERS 91769–B), and other current instructions.

Physical and Psychological

(2) Commands must insure that applicants for all types of diving duty are properly screened prior to being ordered to diving instruction. To effect such screening, order applicants to the nearest activity having facilities to conduct the following:

(*a*) *Physical examination.*—This must be administered by a medical officer in accordance with the Manual of the Medical Department Article 15–30 to determine fitness for diving training.

(*b*) *Recompression chamber pressure test.*—Candidates shall be subjected to a pressure of 50 psi.

(*c*) *Oxygen tolerance test.*—At the time of his initial examination, each candidate for diving training must demonstrate his ability to tolerate breathing pure oxygen at a simulated depth of 60 feet for 30 minutes at rest. The purpose of this test is to eliminate from diving duty those individuals who are susceptible to oxygen intoxication to a degree that may be hazardous to themselves and others. To maintain uniform standards, certain procedures must be followed. The oxygen must be supplied through a demand valve (see 1.6.18). Oxygen masks and systems employing a rebreathing bag must not be used. If a man has a convulsion or demonstrates definite preconvulsive signs (i.e., twitching of lips or limbs) during the test, he has failed. The test must not be repeated. If during the test the candidate complains of symptoms such as nausea, tingling sensations, dizziness, or others, the test may be terminated and repeated at a later date at the discretion of the medical officer.

(*d*) *A test dive in a diving suit under the guidance of a qualified officer.*—In this connection, it has been repeatedly demonstrated that a man showing any reluctance or timidity in making his initial dive seldom becomes an acceptable diver.

(*e*) *Interview by a qualified diving officer to ascertain, insofar as possible, the attitude and motivation of the applicant.*—Because of the nature of the duties and responsibilities of each officer and man engaged in diving, the psychological fitness of each officer and man for diving training should be carefully appraised. All diving candidates must be volunteers. The individual should have arrived at his decision for diving training after mature deliberation, and should be motivated by a real desire for this duty. Emotional maturity, stability, dependability, and at least normal intelligence are necessary. Psychiatric conditions or personality traits that might prevent satisfactory adjustment to diving duty are disqualifying factors.

NOTE

Section B of this appendix is taken from the Manual of the Medical Department, article 15–30, and covers the physical and medical qualifications for diving. Section C of this appendix is taken from the Bureau of Naval Personnel Manual, article C–7408, and outlines the requirements which must be met by the applicant to become a diver and to retain that designation.

F-B. DIVING DUTY, MEDICAL

(1) All accepted candidates for duty that involves diving or underwater swimming shall conform to the following standards:

(*a*) *History of disease.*—Any of the following shall be disqualifying:

1. Tuberculosis, asthma, chronic pulmonary disease.

2. Chronic or recurrent sinusitis, otitis media, otitis externa.

3. Chronic or recurrent orthopedic pathology.

4. Chronic or recurrent gastrointestinal disorder.

5. Chronic alcoholism.

6. No candidate shall be accepted with a history of syphilis, unless there has been adequate treatment and no signs of activity or organic involvement are discovered.

(*b*) *Age.*—Candidates beyond the age of 30 years shall not be considered for initial training in diving, the most favorable age being from 20 to 30. All divers upon reaching the age of 40 shall be examined in accordance with subarticle 15–30(4). For officers undergoing training in deep-sea diving for the specific purpose of becoming diving supervisors or salvage officers, the upper age limit shall be 39 years. In cases where the candidate's age is 40 or more, the provisions of subarticle 15–30(4) below shall apply.

(*c*) *Weight.*—Diving candidates should be rugged individuals without tendency toward obesity. Fat absorbs about five times the volume of nitrogen as does lean tissue. Because of the low circulatory rate of fatty tissue, nitrogen is eliminated very slowly, thus increasing the incidence of bends. It is considered in general that candidates should present no greater than 10 percent variation from standard age-height-weight tables. Consideration will be given, however, to applicants whose overweight is considered to be due to heavy bone and muscular structure.

(*d*) *Vision.*—A minimum of 20/30 vision bilateral, corrected to 20/20, shall be required. This requirement is not made for underwater work but for the retention of relatively high physical standards for hazardous work in connection with diving and salvage operations. Ophthalmoscopic examination shall be normal.

(*e*) *Color vision.*—Normal color perception is required of all candidates.

(*f*) *Teeth.*—A complete dental examination shall be conducted by a dental officer, if available. If a dental officer is not available, the examination shall be conducted by a medical officer. Acute infections or disease of the soft tissues of the oral cavity are disqualifying until remedial treatment is completed. Advanced oral diseases and generally unserviceable teeth shall be cause for rejection. Applicants with moderate malocclusion, or extensive restorations and replacements by bridges or dentures, may be accepted if such do not interfere with effective use of self-contained underwater breathing apparatus (scuba).

(*g*) *Ears.*—Acute or chronic disease of the auditory canal, membrana tympani, middle or internal ear shall be disqualifying. Perforation or marked scarring and/or thickening of the drum shall be disqualifying. The eustachian tubes must be freely patent for equalization of pressure changes. Hearing of each ear shall be normal.

(*h*) *Nose and throat.*—Obstruction to breathing or chronic hypertrophic or atrophic rhinitis shall disqualify. Septal deviation is not disqualifying in the presence of adequate ventilation. Chronically diseased tonsils shall be disqualifying pending tonsillectomy. Presence or history of chronic or recurrent sinusitis is cause for rejection.

(*i*) *Respiratory system.*—The lungs shall be normal as determined by physical examination and 14- by 17-inch chest X-ray.

(*j*) *Cardiovascular system.*—The cardiovascular system shall be without significant abnormality in all respects as determined by physical examination and tests. The blood pressure shall not exceed 145 mm systolic, or 90 mm diastolic. In cases of apparent hypertension, repeated daily blood-pressure determinations should be made before final decision. It should be kept in mind that a valuable indication of undesirable excitable temperament is often revealed by vasomotor manifestations (see (*n*) below). Persistent tachycardia and arrhythmia except of sinus type, evidence of arteriosclerosis (an ophthalmoscopic examination of the retinal vessels shall be included in the examination), varicose veins, marked or symptomatic hemorrhoids shall be disqualifying.

(*k*) *Gastrointestinal system.* — Candidates subject to gastrointestinal disease shall be disqualified.

(*l*) *Genitourinary system.*—The following shall be disqualifying:

1. Chronic or recurrent genitourinary disease or complaints (normal urinalysis required).

2. Active venereal disease or repeated venereal infection.

3. History of clinical or serological evidence of active or latent syphilis within the past 5 years, or of cardiovascular or central nervous system involvement at any time. An applicant who has had syphilis more than 5 years before must have negative blood and spinal fluid serology.

(*m*) *Skin.*—There shall be no active acute or chronic disease of the skin on the basis of infectiveness and/or offensiveness in close working conditions and interchange of diving apparel.

(*n*) *Temperament.*—The special nature of diving duties requires a careful appraisal of the candidate's emotional, temperamental, and intellectual fitness. Past or recurrent symptoms of neuropsychiatric disorder or organic disease of the nervous system shall be disqualifying. No individual with a history of any form of epilepsy, head injury with sequelae, or personality disorder shall be accepted. Neurotic trends, emotional immaturity or instability and asocial traits, if of sufficient degree to militate against satisfactory adjustment, shall be disqualifying. Stammering or other speech impediment which might become manifest under excitement is disqualifying. Intelligence must be at least normal.

(*o*) *Ability to equalize pressure.*—All candidates shall be subjected in a recompression chamber to a pressure of 50 psi to determine their ability to clear their ears effectively and otherwise to withstand the effects of pressure. Due consideration must be given to the presence of an upper respiratory infection which temporarily may impair the ability to equalize pressure because of congestion of the eustachian tube.

(*p*) *Susceptibility to oxygen.*—Individual susceptibility to oxygen shall be tested by determining candidate's ability to breathe oxygen without untoward effects at a pressure of 60 feet (27 pounds) for a period of 30 minutes.

(2) Reexamination of all divers shall be conducted in January of each year in accordance with standards set forth above. Pressure and oxygen-tolerance tests may be omitted from the annual physical examination for those divers who have maintained their diving qualifications in accordance with current BUPERS directives. A notation of physical examination shall be placed in NAVMED 1346 and Standard Form 600 of the Health Record.

(3) Divers shall ordinarily be examined prior to each unusually hazardous dive. Examination of divers shall be made at the discretion of the medical officer prior to the start of extensive rescue, salvage, or diver-training operations. The medical officer should make observations, by personal interview if possible, of all divers prior to their initial dive each day.

(4) Qualified divers who desire to continue in that specialty and are about to reach the age

of 40 shall be examined by a board of medical officers appointed by the senior officer present. At least one member of the board shall be qualified as a deep-sea diver or in submarine medicine. The report of the examination on Standard Form 88 with the recommendation of the board as to whether the individual is or is not physically qualified to continue as a diver shall be forwarded to the Bureau of Medicine and Surgery for final decision and in time to reach BUMED before the man attains the age of 40. A certain latitude may be allowed for a diver of long experience and a high degree of efficiency in diving. He must be free from any diseases of the cardiovascular, respiratory, genitourinary, and gastrointestinal systems, and of the ear. His ability to equalize air pressure must be maintained. A moderate degree of overweight may be disregarded if the diver is otherwise vigorous and active.

F–C. QUALIFICATIONS FOR DIVERS

(1) Qualified divers are divided into six classes according to their degree of qualification as follows:

(*a*) Master Divers (5341).

(*b*) Divers First Class (5342).

(*c*) Medical Deep-Sea Diving Technician (8493).

(*d*) Salvage Divers (mobilization only).

(*e*) Divers Second Class (5343).

(*f*) Scuba Divers (5345).

NOTE

When a man has been trained and qualified as a diver, an entry shall be made on page 13 of his service record as follows:

DATE: Qualified as ______________ to
(class diver)
a depth of ________ feet. Qualification lapse date __________ Authorized assignment to NEC ________ Diving Billets (in NAVPERS 576s) and entitled to receive appropriate pay when performing the duties of the billet. Assignment of NEC ________ recommended to BUPERS. AUTH: Article C–7408(1) BUPERS Manual.

SIGNATURE ______________.

(2) Navy Enlisted Classifications which include a degree of diving qualification, collateral to basic classification, are as follows:

(*a*) Underwater Demolition Team Swimmer (5321).

(*b*) Underwater Demolition Team Swimmer/Explosive Ordnance Disposal Technician (5322).

(*c*) Explosive Ordnance Disposal Technician (5332).

(*d*) Underwater Photographer (8136).

(*e*) Hospital Corpsman, Special Operations Technician (8492).

NOTE

When a man has been trained and qualified in one of the above categories, an entry shall be made on page 13 of his service record as follows:

DATE: Qualified as ______________ to a depth of ________ feet. Qualification lapse date ________ Authorized assignment to NEC ________ Billet (in NAVPERS 576s) and entitled to receive appropriate pay when performing the duties of the billet. Assignment of of NEC ________ recommended to BUPERS. AUTH: Article C–7408(2) BUPERS Manual.

SIGNATURE ______________.

(3) *Classification and designation:*

(*a*) After a BUPERS Report 1080–14 listing the appropriate NEC has been received and page 4 service record entry made assigning the appropriate NEC, this code will not be removed because the man's qualification as a diver lapses, but will be retained as long as he is capable of being requalified as a diver. Personnel no longer volunteering or capable of requalifying for diving duties shall be reported to the Chief of Naval Personnel in order that their diver NEC's can be revoked.

(*b*) The enlisted designator shall be placed immediately after the man's rating abbreviation in parentheses and shall appear with his rating abbreviation on all service-record pages and on all correspondence pertaining to him thereafter as long as he remains a qualified diver. In the case of a diver's failure to requalify by the end of his qualification period, the DV designator must be removed on the date following the last date of the qualification period. The DV designator may, however, be restored by the commanding officer upon completion of the necessary requalification dives not later than 1 year after lapse of qualification. Should qualification lapse continuously for a period of 1 year, the individual must be retrained in accordance with paragraph (6) following. All actions which result in the assignment or removal of the enlisted designator (DV) shall be reported immediately to the cognizant PAMI by an appropriate diary entry.

(4) *Training and selection:*

(*a*) In the training and selection of men as divers, commanding officers and examining boards shall be guided strictly by the Bureau of Naval Personnel Manual, the Manual of the Medical Department, the Bureau of Naval Personnel Formal Schools Catalog NAVPERS 91769 (current series), and other current instructions.

(*b*) An officer will be assigned responsibility for any and all diving. That officer will study all diving publications available and will make every effort to assure himself that all diving is conducted in accordance with good diving practice. He will particularly insure that the man in charge of the actual diving operations is a diver whose competency, responsibility, and reliability are commensurate with the particular operation.

(5) *Physical requirements:*

No man shall be allowed to dive unless he has been found physically qualified by examination in accordance with article 15–30 of the Manual of the Medical Department within the preceding 12 months, or following any intervening illness or accident considered likely to affect physical qualification for diving.

(6) *Tenure, qualification, and requalification:*

Periodic qualification of all divers is necessary to insure continuous proficiency and maximum safety. Divers will be qualified for 6-month periods. An entry will be made in the service record to show the period of a diver's qualification. When dives are conducted in accordance with the requirements listed below within the period of qualification, a diver will be considered qualified for another 6-month period, beginning on the date his qualification would have lapsed. If dives are conducted in accordance with the requirements listed below within 1 year of the date on which qualification lapsed, the diver will be considered requalified, and an entry to that effect will be made in the service record. If a diver's qualification has lapsed continuously for more than 1 year, he will be retrained and redesignated in accordance with paragraphs (8) through (12) herein as applicable, but only after his permanent interest in diving and his sincere desire for redesignation are established. Entitlement to special pay for diving duty depends upon the maintenance of qualification by actual performance of dives according to the tables listed below. Accordingly, no extensions of diver qualifications are authorized except by the actual performance of prescribed qualification dives. Four dives in accordance with the tables listed below are required to maintain diver qualifications, except that UDT swimmers, EOD technicians, underwater photographers, hospital corpsmen special-operations technicians, and scuba divers are required to perform a combination of dives and swims using scuba equipment.

(*a*) *Master divers, divers first class, and medical deep-sea diving technicians, basic.*—Four dives are required under any of the depth-time requirements below:

Depth of water, feet	Minimum bottom time, minutes
100 to 150	45
150 to 170	30
170 to 200	15
200 plus	10

A minimum of two of the required four dives shall be made using helium-oxygen as a breathing medium when attached to helium-oxygen equipped vessels or activities.

(*b*) *UDT swimmers.*—Candidates for this classification must execute the following:

	Minimum depth or distance	Minimum bottom time
(1) Day:		
2 dives	120 feet	10 minutes.
2 scuba swims on compass course.	1—1,000 yards 1—1,500 yards	
(2) Night: 2 scuba swims on compass course.	1—1,000 yards 1—1,500 yards	

(*c*) *EOD technicians.*—The following are required to be qualified in this category:

1. Dives:

Two dives, of 120 feet for 10 minutes.

Two dives, of 30 to 130 feet (EOD/NWD problems in connection with the location of, and disposal or rendering safe of ordnance).

2. Scuba swims: Two, of 500 yards each.

(*d*) *Salvage divers and divers second class, basic.*—Four dives (search or salvage work problems) are required, each being at a depth between 30 and 150 feet, and lasting a minimum of 45 minutes.

(*e*) *Scuba divers, underwater photographers, and hospital corpsmen special operations technicians.*—Requirements for these qualifications are—

1. Dives:

One dive of 50 to 70 feet for 10 minutes.

One dive of 70 to 130 feet for 5 minutes.

2. Scuba swims: Two scuba swims of 500 yards each.

(*f*) Master divers, divers first class, and medical deep-sea diving technicians may take requalifying dives in accordance with subparagraph (*d*) above when permanently attached to activities that are part of the shore establishment when available water depths or equipment limitations preclude requalification in accordance with subparagraph (*a*) above. This provision does not apply to activities having wet pressure tanks installed. Other classes of divers in the above category may make requalifying dives in accordance with subparagraph (*d*) above; but must in addition complete those scuba swims specified in subparagraph (*b*), (*c*), or (*e*) above as applicable.

(*g*) Dives and swims made during regular diving operations will count for retaining diver qualification, provided they meet the requirements of subparagraphs (*a*) through (*e*) above. Minimum depths and duration of qualification and requalification dives outlined therein are not intended to prescribe operational diving limitations.

(*h*) Commands are expected to insure that divers maintain proficiency in the use of all types of diving equipment for which qualified, insofar as the individual activity's authorized equipment will permit. Training and requalification diving should be planned to include salvage, search and repair exercises utilizing deep-sea, lightweight, scuba, and helium-oxygen equipment if so outfitted.

(*i*) All divers should receive free-ascent training at one of the submarine-escape training tanks when possible. Under no circumstances will this training be conducted at other activities unless a recompression chamber is readily available and the training is under the direct supervision of a diving officer and submarine medical officer assisted by well-qualified instructors in free-ascent techniques.

(7) *Revocation of designation:*

Commanding officers may recommend to the Chief of Naval Personnel the revocation of the designation of any class of diver with reasons therefor. Whenever a designation is revoked, an entry will be made on the administrative-remarks page of the service record, showing date of revocation and reasons therefor, and reported as a miscellaneous change to the cognizant PAMI.

(8) *Distinguishing mark:*

An enlisted man who qualifies as a diver will be authorized to wear a distinguishing mark as prescribed by the U.S. Navy Uniform Regulations, 1959. Authorization to wear the distinguishing mark will continue throughout the tenure of qualification. Master divers, who through no fault of their own, are physically disqualified from continuance in diving, may continue to wear the master diver distinguishing mark.

(9) *Requirements for master divers* (effective 1 February 1962):

(*a*) *Designation.*—Master divers are the most competent divers first class who have been recommended by their commanding officer and approved by the Chief of Naval Personnel for designation as master diver to fill an authorized billet at a diving activity. Commanding officers of diving-type activities may recommend by letter to the Chief of Naval Personnel any diver first class for designation as master diver who fulfills the qualification requirements listed below. No waiver of these requirements is authorized except that the Chief of Naval Personnel will consider, on an individual basis when so recommended by the commanding officer, the waiver of one-type vessel service requirement in the case of individuals whose performance is of such excellence as to warrant special consideration. The letter of recommendation will note the fulfillment of each requirement and will contain a statement of duties performed as a diver.

(*b*) *Eligibility requirements*.—The candidate must—

1. Be a chief petty officer, pay grade E–7 or above other than hospital corpsman, a minimum of 1 year.

2. Have served a minimum of 2 years with the designation and qualification of diver first class.

3. Have served as a qualified diver first class a minimum of 12 months aboard a helium-oxygen-equipped diving vessel, and as a qualified salvage diver, or above, a minimum of 12 months aboard an ARS or ARSD-type diving vessel.

4. Have averaged during the preceding year at least 3.5 in each of the following with no individual mark less than 3.2: professional performance; leadership; and supervisory ability.

5. Be a designated diver first class.

6. Be a graduate of the master diver qualification course conducted at Naval School, Diving and Salvage, Washington, D.C.

(*c*) *Qualification factors*.—The qualification factors are as follows:

1. Demonstrate ability to take charge of all phases of helium-oxygen diving.

2. Demonstrate ability to plan and take charge of all diving operations.

3. Demonstrate ability to take charge of operation and maintenance of a submarine-rescue chamber.

4. Demonstrate knowledge of all Navy-procured types of self-contained underwater breathing equipment, including their advantages and limitations.

5. Know the methods and materials used in unbeaching ships on strand under various conditions of beach, sea, and water, and refloating sunken vessels.

6. Demonstrate knowledge of the types of compressors used habitually in diving operations, including the various filtering methods and the necessary precautions to observe.

7. Understand the principles of the general gas law and its derivatives (Boyle's and Charles' laws).

8. Understand the principles of Dalton's law of partial pressures and Henry's law of fluid saturation.

9. Understand the theory of inert-gas saturation and desaturation of body fluids and tissues.

10. Understand the principles involved in the computation of various decompression tables.

11. Recognize the different forms of decompression sickness and know the treatment required.

12. Understand the effect upon the respiratory system of such poisonous gases as may be encountered in diving, and know the treatment required.

13. Know the name and use of equipment required for safe diving operations.

14. Know the causes, symptoms, and treatment of, and preventive measures for, all types of diving accidents.

15. Have a comprehensive knowledge of the scope, content, and application of Navy publications and instructions pertaining to diving, such as the Diving Manual (NAVSHIPS 0994–001–9010) and applicable sections of the Naval Ship Systems Command Technical Manual, Manual of the Medical Department, and Bureau of Naval Personnel Manual.

(10) *Requirements for divers first class:*

(*a*) *Designation*.—Divers first class are trained, qualified, and designated at the Naval School, Diving and Salvage, Washington, D.C. No man will be placed in training for diver first class at any other place without prior authority from the Chief of Naval Personnel.

(*b*) *Eligibility requirements*. — Personnel must meet the following requirements to be eligible for the special course of instruction for diver first class:

1. Be recommended by his commanding officer.

2. Have a minimum obligated service of 18 months upon entry into the special course for diver first class.

3. Meet physical standards specified in article 15-30, Manual of the Medical Department, as required for diving duty.

4. Be a qualified swimmer first class.

(*c*) *Qualification factors.*—The qualification factors are as follows:

1. Withstand pressure equal to 300 feet of water while breathing air.

2. Dive and accomplish work using self-contained underwater breathing apparatus (scuba), shallow-water diving equipment, deep-sea diving equipment, and helium-oxygen diving equipment.

3. Dive and accomplish work at a depth of 200 feet of water while breathing air.

4. Dive and accomplish work at a depth of 320 feet of water while breathing helium-oxygen mixture.

5. Demonstrate proficiency in the use of all underwater tools, both in the shop and under actual diving conditions; the operation and maintenance of a submarine-rescue chamber; and marlinespike seamanship commonly used aboard salvage and rescue vessels.

6. Demonstrate knowledge of diving physics, particularly showing proficiency in mixing and analyzing synthetic breathing mixtures and in computing pressures of gases required to operate underwater cutting torches at various depths.

7. Demonstrate knowledge of diving physiology; know the use of standard decompression tables; recognize symptoms of decompression sickness; and know the treatment required for all common diving accidents.

8. Demonstrate proficiency in the use of the recompression chamber for treatment of diving accidents and for surface-decompression procedures.

9. Care for, test, repair, and adjust all diving equipment and determine whether it is safe for use.

10. Equip a boat for both self-contained and surface-supplied diving.

11. Demonstrate ability to direct two or more divers on the bottom in their tasks.

12. Know the advantages, limitations, and techniques involved in the use of helium-oxygen, surface-supplied air, and self-contained diving apparatus.

13. Demonstrate ability to perform all required rigging for salvage and rescue operations.

14. Demonstrate ability to perform and supervise independent diving operations using surface-supplied air, helium-oxygen, and self-contained apparatus.

15. Plan simple diving operations.

16. Understand safety precautions necessary in handling of gases and use of apparatus required for underwater cutting.

17. Perform proficiently such underwater work as taking measurements, making templates, making fittings and placing shores, pouring cement, using excavating nozzles, and removing and repairing ship's appendages.

18. Maintain, rig, and operate salvage pumps, air compressors, winches, jacks, beach gear, and high line assemblies.

19. Rig for lifts encountered in salvage operations up to a maximum of 300 tons, including underwater lifts.

20. Install necessary pumps and air compressors, and lay necessary beach gear for hauling off stranded vessels. Understand in general the salvaging of vessels, including stability, structural strength, and groundings.

21. Enter submerged vessels with discrimination and only as decided and planned by the supervising officer.

22. Demonstrate proficiency in the use of explosives under water and have knowledge of materials and methods used in such varied salvage activities as harbor clearance, harbor-bottom alteration, rock and concrete blasting, steel and timber cutting, and removal of propellers for replacement.

(11) *Requirements for medical deep-sea diving technicians:*

(*a*) *Designation.*—Medical deep-sea diving technicians are designated by the Bureau of Medicine and Surgery after satisfactory completion of the prescribed course of instruction at the Naval School, Diving and Salvage, Washington, D.C.

(*b*) *Eligibility requirements.* — Personnel must meet the following requirements to be eligible for the medical deep-sea diving technician course of instruction:

1. Volunteer for and be recommended by his commanding officer.

2. Meet basic eligibility requirements as set forth in current BUMED directives.

(*c*) *Qualification factors.*—Medical deep-sea diving technicians shall be required to meet the same qualification factors as divers first class except as modified below:

1. Completely meet qualification factors *1*, *2*, *3*, *4*, *5*, *9*, and *10* above. Also demonstrate proficiency in the operation and maintenance of the submarine-rescue chamber.

2. Demonstrate more extensive knowledge and greater proficiency in qualification factors *6*, *7*, *8*, *12*, and *16* above.

3. Be exempt from qualification factors *11*, *13*, *14*, *15*, *17*, *18*, *19*, and *20*.

4. Demonstrate knowledge of health and safety aspects of the use of underwater tools, the entering of submerged vessels, and use of explosives under water.

(12) *Requirements for salvage divers:*

(*a*) *The classification.*—This diver classification is being retained only as a category for expansion in event of an increase in diver requirements on mobilization; consequently, initial training of salvage divers has been discontinued.

(*b*) *Eligibility requirements.*—Personnel must have satisfactorily completed the prescribed course in ship salvage.

(*c*) *Qualification factors.*—The qualification factors are as follows:

1. Withstand pressure equal to 200 feet of water while breathing air.

2. Demonstrate mechanical ability.

3. Dive and accomplish work using self-contained underwater breathing apparatus (scuba), shallow-water diving equipment, and deep-sea diving equipment.

4. Demonstrate proficiency in the operation and care of machinery and apparatus required for underwater cutting, including oxygen-hydrogen and oxygen-electric torches under water.

5. Understand safety precautions necessary in handling of gases and use of apparatus required for underwater cutting.

6. Perform proficiently such underwater work as taking measurements; making templates; making, fitting, and placing patches; placing shores; pouring cement; using excavating nozzles; and removing and repairing ship's appendages.

7. Maintain, rig, and operate salvage pumps, air compressors, winches, jacks, beach gear and high line assemblies.

8. Rig for lifts encountered in salvage operations up to a maximum of 300 tons, including underwater lifts.

9. Install necessary pumps and air compressors, and lay necessary beach gear for hauling off stranded vessel. Understand in general the salvaging of vessels, including stability, structural strength, and groundings.

10. Enter submerged vessels with discrimination, and only as decided and planned by the supervising officer.

11. Demonstrate proficiency in the use of explosives under water and have knowledge of materials and methods used in such varied salvage activities as harbor clearance, harbor-bottom alteration, rock and concrete blasting, steel and timber cutting, and propeller removal and replacement.

12. Demonstrate knowledge of diving physics and of diving physiology; know the use of standard decompression tables; recognize symptoms of decompression sickness; and know the treatment required for all common diving accidents.

13. Demonstrate proficiency in the use of the recompression chamber for treatment of diving accidents and for surface decompression procedures.

14. Care for, test, repair, and adjust all diving equipment and determine whether it is safe for use.

NOTE

Salvage divers will not dive beyond the depths for which qualified, as stated in their service record, except for qualification purposes which will be limited to maximum depths of 200 feet. In emergencies, the senior officer shall be the judge of a deviation from the above.

(13) *Requirements for divers second class:*

(*a*) *Designation.*—Divers second class are trained, qualified, and designated by any command having the proper equipment and competent personnel for safe and efficient instruction so designated by the Chief of Naval Personnel.

1. The following personnel and equipment are required on vessels and naval stations authorized to train, qualify, and designate divers second class:

A designated diving officer.

A master diver or diver first class who will serve as an instructor.

In general, the amount of equipment will depend upon the number of personnel being trained and qualified, but the minimum equipment shall include the following:

Two deep-sea diving outfits.

Two lightweight diving outfits.

Three open-circuit demand self-contained underwater breathing apparatus.

One recompression chamber (shall be on board ships authorized to conduct such training or, in the case of authorized activities, shall be in the nearby area).

Sufficient copies of the Diving Manual, NAVSHIPS 0994–001–9010, that there will be one for each trainee.

Copies of curriculum for divers second class, NAVPERS 93206.

(*b*) *Eligibility requirements.*—Enlisted personnel in pay grade E–3 and above who are qualified as swimmers first class, and meet the physical standards for duty as set forth in Article 15–30, Manual of the Medical Department, U.S. Navy, are eligible.

(*c*) *Qualification factors.*—Qualification factors for divers second class are as follows:

1. Understand the care, preservation, and use of all air diving equipment such as compressors, hose, helmets, suits, and scuba.

2. Test, repair, and adjust all air diving equipment and determine whether it is safe for use.

3. Know the nomenclature of diving equipment and the function of component parts.

4. Dress and tend diver expertly.

5. Know standard diving signals.

6. Know the instructions for keeping diving log and entries required.

7. Understand the theory and practice of decompression, and use of the decompression table.

8. Know the cause, symptoms, treatment, and prevention of air embolism.

9. Know the dangers of oxygen poisoning during the administration of oxygen under pressure, and its usual symptoms, warnings, and treatment.

10. Demonstrate the mouth-to-mouth method of artificial respiration.

11. Knowledge of first aid related to the treatment of common diving accidents.

12. Know the physics of diving.

13. Know the methods and procedures employed in searching for and recovering of objects from the bottom.

14. Know how and when to use a recompression chamber. Know how to properly administer oxygen for decompression and treatment purposes.

15. Demonstrate practical application of marlinespike seamanship to diving operations.

16. Perform work at depth of 50 feet of water for 1 hour, which will constitute a qualifying dive.

17. Know the contents and use of the Diving Manual.

18. Estimate an underwater situation and give an intelligent description of same. Training and examination of this ability requires a number of actual or simulated practical diving jobs, such as applying small patches, clearing screws, and taking measurements.

19. Use oxygen-electric torch under water.

20. Use and know the advantages, limitations, and safety precautions of open-circuit demand scuba.

NOTE

Divers second class will not dive beyond the depths for which qualified as stated in their service record, except for qualification purposes which will be limited to maximum depths of 200 feet. In emergencies, the senior officer present shall be the judge of a deviation from the above.

(14) *Requirements for scuba divers:*

(*a*) *Designation.*—Personnel are trained and designated as scuba divers at the U.S. Naval School, Underwater Swimmers, U.S. Naval Station, Key West, Fla., and such other activities specifically authorized by the Chief of Naval Personnel.

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(*b*) *Training requirements.*—The following personnel and equipment are required to be on board ships and naval activities authorized, in accordance with subparagraph (*a*) above, to conduct training in the use of scuba equipment:

1. A designated diving officer assisted by an experienced scuba diver or above who will serve as an instructor.

2. Sufficient copies of part 3 of the Diving Manual, NAVSHIPS 0994–001–9010, so that there will be one for each trainee.

3. Copies of curriculum for scuba divers, NAVPERS 93206.

4. Recompression chamber (shall be on board ships authorized to conduct such training or in the case of authorized activities shall be in the nearby area).

(*c*) *Eligibility requirements.*—Candidates must meet the following qualifications:

1. Enlisted personnel in pay grade E–3 and above, who are designated strikers or petty officers in one of the source ratings specified in the Bureau of Naval Personnel Formal Schools Catalog, NAVPERS 91769 (current series).

2. All personnel must meet the physical and psychological standards prescribed in Article 15–30, Manual of the Medical Department, U.S. Navy; must be at least swimmers first class; and must comply with selection standards for diving candidates.

(*d*) *Qualification factors.*—Qualification factors for scuba divers are as follows:

1. Swim 1,000 yards on surface in open water without fins but with face mask, lifejacket, and knife as necessary equipment.

2. Swim 500 yards under water using fins, face mask, and scuba.

3. Clear scuba under water.

4. Ditch and don scuba under water.

5. Make a positive-buoyancy free ascent from a depth of at least 35 feet.

6. Swim with scuba to a depth of 100 feet.

7. Conduct day and night general underwater search and detailed ship-bottom search.

8. Use underwater compass, depth indicators, and associated underwater equipment.

9. Perform routine inspection, adjustment, field and shop maintenance on scuba and underwater accessories.

10. Know safety precautions to be observed in use of scuba.

11. Understand the theory and practice of decompression, and use decompression tables.

12. Knowledge of divers' diseases including oxygen and carbon dioxide toxicity, nitrogen narcosis, decompression sickness, and air embolism; and of emergency remedial procedures.

13. Know underwater hazards.

14. Understand use of current and tide tables.

NOTE

Scuba divers will not dive beyond the depths for which qualified in their service record. Normal working depths for scuba divers breathing compressed air is considered to be less than 130 feet.

(15) *Records:*

All diving-type activities will maintain the Activity Diving Log, NAVSHIPS 9940/1 (Rev. 2–67), as a permanent official record of each individual command. Instructions for use of the Activity Diving Log, NAVSHIPS 9940/1 (Rev. 2–67), are contained in the U.S. Navy Diving Manual, NAVSHIPS 0994–001–9010.

(16) *Substantiation of entitlement to special pay for diving duty:*

A personnel diary entry of Military Pay Order (DD Form 114) will be submitted in accordance with provisions contained in the Navy Comptroller Manual. In addition, in all instances wherein special pay for diving is affected, a concurrent page 13 entry will be made in the service record of the individual concerned.

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