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U.S. NAVY DIVING MANUAL
VOLUME 1
(AIR DIVING)

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U.S. Navy Diving Manual, Revision 3 (NAVSEA 0994-LP-001-9010 and 9020)

Revision 3 of the U.S. Navy Diving Manual presents comprehensive information on air and mixed-gas diving operations. The manual continues to be presented in two volumes: Volume 1 (Air Diving) and Volume 2 (Mixed-Gas Diving).

This revised manual contains new data and information from all groups within the Navy diving community, and reflects state-of-the-art diving capabilities of the U. S. Navy today. New equipments appearing for the first time include the Underwater Breathing Apparatus (UBA) MK 20 MOD 0, UBA MK 21 MOD 1, the Light Weight Diving System (LWDS) MK 3 MOD 0 and the Transportable Recompression Chamber System (TRCS). New appendices have been included to increase the data available to users in the Fleet. Particular attention is directed to the changes in the deployment of standby divers in ships husbandry diving, changes in treatment tables and new correction factors and guidance relating to the use of pneumofathometers.

Diving equipment, capabilities and techniques are ever changing and today's information may soon be overtaken by new advances. This manual provides the best information available today, however it will be updated periodically to reflect the myriad of changes anticipated in the years ahead.

We wish to thank the large number of fleet divers that provided input to this revision. Their review has enabled us to produce a significantly better product in a more usable format. Particular thanks are extended to CAPT Ed Flynn, CAPT Ed Thalmann, CAPT Claude Harvey, LCDR Sue Trukken-Schreck, ENCM (MDV) Don Roberts, MMCM (MDV) Dave Buehring, MMCM (MDV) Bobby Moore, HTCM (MDV) Lino Mattioni and HTCM (MDV) Dave Willette whose efforts produced the real core of the changes to this volume. Thanks also to CAPT Dick Fiske, SUPSALV for his leadership, assistance and encouragement. The real big gun, however, who pushed it along, day in and day out and without whom it would still be just a huge pile of notes and disjointed correspondence was our own GMCM (MDV) Billy Brooks. Well Done!

Alan J. Dietrich

ALAN J. DIETRICH
Director of Diving Programs

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SAFETY SUMMARY

STANDARD NAVY SYNTAX

Since this manual will form the technical basis of many subsequent instructions or directives, it utilizes the standard Navy syntax as pertains to permissive, advisory, and mandatory language. This is done to facilitate the use of the information provided herein as a reference for issuing Fleet Directives. The concept of word usage and intended meaning which has been adhered to in preparing this manual is as follows:

> "Shall" has been used only when application of a procedure is mandatory.
>
> "Should" has been used only when application of a procedure is recommended.
>
> "May" and "need not" have been used only when application of a procedure is discretionary.
>
> "Will" has been used only to indicate futurity; never to indicate any degree of requirement for application of a procedure.

The usage of other words has been checked against other standard nautical and naval terminology references.

GENERAL SAFETY

This Safety Summary contains all specific WARNINGS and CAUTIONS appearing elsewhere in this manual, and are referenced by page number. Should situations arise that are not covered by the general and specific safety precautions, the Commanding Officer or other authority will issue orders, as deemed necessary, to cover the situation.

SAFETY GUIDELINES

Extensive guidance for safety can be found in the OPNAV 5100 series instruction manual, Navy Safety Precautions.

SAFETY PRECAUTIONS

The WARNINGS, CAUTIONS and NOTES contained in this manual are defined as follows:

WARNING

Identifies an operating or maintenance procedure, practice, condition, or statement, which, if not strictly observed, could result in injury to or death of personnel.

CAUTION

Identifies an operating or maintenance procedure, practice, condition, or statement, which, if not strictly observed, could result in damage to or destruction of equipment or loss of mission effectiveness, or long-term health hazard to personnel.

NOTE

An essential operating or maintenance procedure, condition, or statement, which must be highlighted.

WARNING

Breathholding and skip-breathing frequently lead to hypercapnia and are not to be used at any time (page 5-28).

WARNING

During ascent, the diver without the mouthpiece must exhale to offset the effect of decreasing pressure on the lungs which could cause an air embolism (page 5-34).

WARNING

This relief valve gag valve must remain in the open position at all times during normal chamber operation and when chamber is secured. Close only in the event of relief valve failure and chamber depressurization is imminent (page D-13).

WARNING

This procedure is to be performed with an unmanned chamber to avoid exposing occupants to unnecessary risks (page D-13).

WARNING

Fire/Explosion Hazard. No matches, lighters, electrical appliances, or flammable materials permitted in chamber (page D-22).

CAUTION

Avoid overinflation and be aware of the possibility of blowup when breaking loose from mud. It is better to call for aid from the standby diver than to risk blowup (page 6-24).

CAUTION

Never attempt to interpolate between decompression schedules (page 7-7).

CAUTION

If the tender is outside of no-decompression limits, he should not be brought directly to the surface. Either take the decompression stops appropriate to the tender or lock in a new tender and decompress the patient leaving the original tender to complete the decompression (page 8-20).

CAUTION

In very cold water, the wet suit is only a marginally effective thermal protective measure and its use exposes the diver to hypothermia and restricts available bottom time. The use of alternative thermal protective equipment should be considered in these circumstances (page J-4).

CAUTION

Prior to the use of variable volume dry suits and hot water suits in cold and ice-covered waters, divers must be trained in their use and be thoroughly familiar with the operation of these suits (page J-5).

CHAPTER ONE

HISTORY OF DIVING

1-1 INTRODUCTION

The origins of diving are firmly rooted in the needs and desires of men to engage in underwater commerce, to conduct salvage and military operations, and to expand the frontiers of knowledge through exploration, research, and development.

No one knows when man first discovered he could swim down and retrieve objects from under the water, but diving as a profession can be traced back more than 5,000 years. These early diving efforts were confined to relatively shallow waters (less than 100 feet), with the divers performing salvage work and harvesting a variety of products including food, sponges, coral, and mother-of-pearl (Figure 1-1).

Figure 1-1. Sixth-Century B.C. vase showing a Greek diver about to descend, probably in search of sponges.

One of the first records of such diving is found in the writings of the Greek historian Herodotus. He tells the story of a diver named Scyllis, who was employed by the Persian King Xerxes to recover sunken treasure in the fifth century B.C.

From the earliest times, divers were active in military operations. Their missions included cutting anchor cables to set enemy ships adrift, boring or punching holes in the bottoms of ships, and building harbor defenses at home while attempting to destroy those of the enemy abroad. Historical records indicate that Alexander the Great not only sent divers down to remove obstacles in the harbor of the city of Tyre, in what is now Lebanon, which he had taken under siege in 332 B.C., but also went underwater himself to view the progress of their work.

Other early divers developed an active salvage industry centered around the major shipping ports of the eastern Mediterranean. By the first century B.C., operations in one area had become so well organized that a scale of payment for salvage work was established by law, acknowledging the fact that effort and risk increased with depth. In 24 feet of water the divers could claim a one-half share of all goods recovered. In 12 feet of water they were allowed a one-third share, and in three feet only a one-tenth share.

1-2 EARLY DEVELOPMENTS

The most obvious and necessary step in broadening the capabilities of a diver was to provide an air supply that would permit him to stay underwater. First efforts used hollow reeds or tubes extending to the surface. The user could remain submerged for an extended period of time, but could accomplish little in the way of useful work. Breathing tubes were employed mainly as a tactic in military operations where they permitted an undetected approach to an enemy stronghold. Men using these tubes were not so much divers as they were soldiers using the water as a cover for their mission.

At first glance it would seem logical that the only thing needed to further extend the range of the diver would be a longer tube. In fact, a number of early designs were created using leather hoods with long flexible tubes supported at the surface by floats (Figure 1-2). There is no record that any of these devices were constructed or tested under actual conditions. The result may well have been the drowning of the user. At a shallow depth of three feet it is essentially impossible to breathe through a tube using only the body's natural respiratory ability, as the weight of the water exerts a total force of almost 200 pounds on the diver's chest. This force increases steadily with depth and is one of the most important factors in diving. Any successful diving operation requires that the pressure be overcome or eliminated. Throughout history imaginative devices were designed to accomplish this, many by some of the greatest minds of the time. At first, the problem of pressure underwater was not fully understood and the designs were impractical.

Figure 1-2. Early Impractical Breathing Device. This 1511 design shows the diver's head encased in a leather bag with a breathing tube extending to the surface.

An entire series of designs was based on the idea of a breathing bag carried by the diver. This concept may be very ancient since an Assyrian frieze of the ninth century B.C. shows what appear to be divers using inflated animal skins as air tanks (Figure 1-3). However, these men were probably swimmers using skins for flotation. It would be impossible to submerge while holding such an accessory.

Figure 1-3. Assyrian Frieze (900 B.C.).

A workable diving system may have made a brief appearance in the later Middle Ages. In 1240, Roger Bacon made reference to "instruments whereby men can walk on sea or river beds without danger to themselves."

Other writers, in the sixteenth and seventeenth centuries, described and published drawings of equipment which foreshadowed later successful developments.

1-2.1 Early Successes. Between 1500 and 1800 the diving bell was developed and placed in use, enabling divers to remain underwater for hours rather than minutes.

The diving bell is bell-shaped with the bottom open to the sea. The first diving bells were large, strong tubs weighted to sink in a vertical position, thereby trapping enough air to permit a diver to breathe for several hours. The principle of the bell is easily observed by pushing an inverted drinking glass into a pan of water. The air inside the glass is compressed slightly by the water, with the pressure equalizing at some point to leave a reservoir of air.

Diving bells are suspended by a cable from the surface and have no significant underwater maneuverability beyond that provided by moving the support ship. The diver can either remain in the bell, if positioned directly over his work, or by holding his breath, can venture outside for short periods of time.

The first reference to an actual practical diving bell was made in 1531, and for several hundred years thereafter, rudimentary but effective bells were used with regularity. In the 1680's, a Massachusetts-born adventurer named William Phipps modified the diving bell technique by supplying his divers with air from a series of weighted, inverted buckets as they attempted to recover treasure valued at $200,000.

In 1690, the English astronomer Edmund Halley developed a diving bell in which the atmosphere was replenished by sending weighted barrels of air down from the surface (Figure 1-4). In an early demonstration of his system, he and four companions remained at 60 fsw in the Thames River for almost 1-1/2 hours. Nearly 26 years later, using an improved version of his bell, Halley, then 65 years old, spent more than four hours at a depth of 66 fsw.

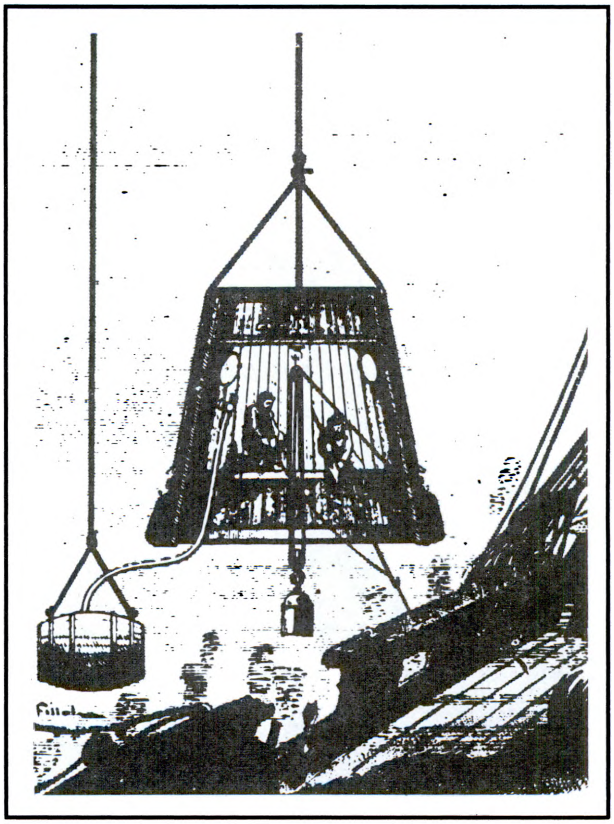


Figure 1-4. Halley's Diving Bell. Improved diving bells used weighted barrels of air to replenish their atmosphere.

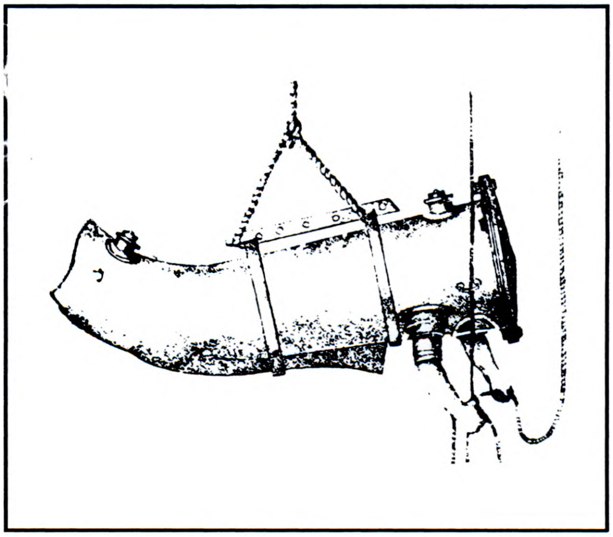


Figure 1-5. Lethbridge's Diving Suit.

In 1715, another Englishman, John Lethbridge, developed a one-man completely enclosed diving dress (Figure 1-5). The Lethbridge equipment was essentially a reinforced, leather covered barrel of air, equipped with a glass porthole for viewing, and two arm holes with watertight sleeves. Wearing this gear, the occupant could accomplish useful work. This apparatus was lowered from a ship and maneuvered in the same manner as a diving bell.

Lethbridge was apparently quite successful with his invention and participated in the salvage of a number of European wrecks. In a letter to the editor of a popular magazine in 1749, the inventor noted that his normal operating depth was ten fathoms (60 feet), with about 12 fathoms the maximum, and that he could remain underwater for 34 minutes.

Several other designs similar to Lethbridge's appeared and were used in succeeding years (Figure 1-6). However, they all suffered from the same basic limitation as the diving bell: the diver had little freedom because there was no practical way to continually supply him with air. A true technological breakthrough occurred at the turn of the nineteenth century with the development of a hand operated pump capable of delivering air under pressure.

1-2.2 The Deep-Sea Diver. The art and practice of salvage diving was well developed as England entered the Industrial Revolution in the mid-eighteenth century. Using diving bells, devices similar to that of Lethbridge, or by skin diving in shallow waters, salvage operators were very active recovering everything from lost anchors to gold and silver. While man has always been fascinated by the search for sunken treasure, such finds were rare. The day-to-day financial rewards came from more mundane but valuable scrap. The brass recovered from the ordnance of a 100-gun ship of the line was worth more than $50,000 in the money of the day (Figure 1-7). With additional military and civilian wrecks littering the shores of Great Britain each year, there was strong incentive for developing a diving dress that would increase the efficiency of salvage operations.

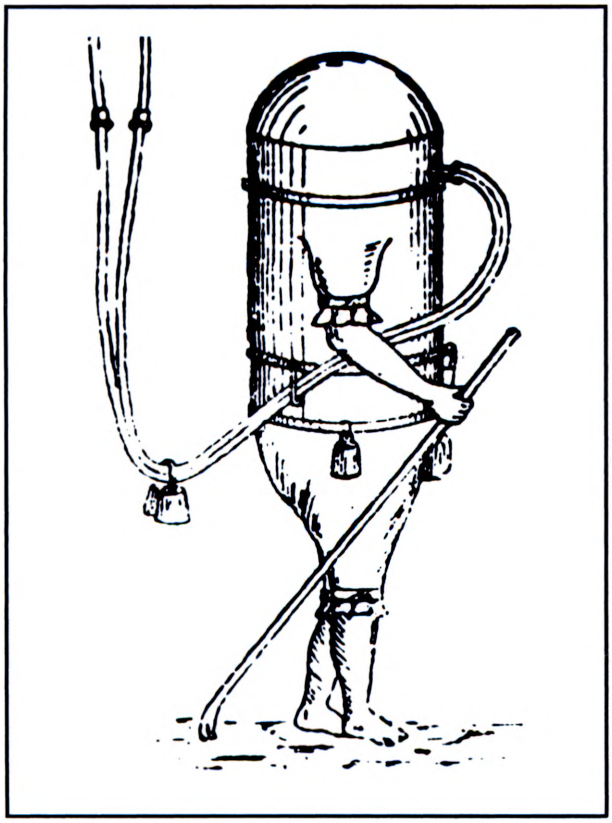


Figure 1-6. Successful Enclosed Diving Dress.

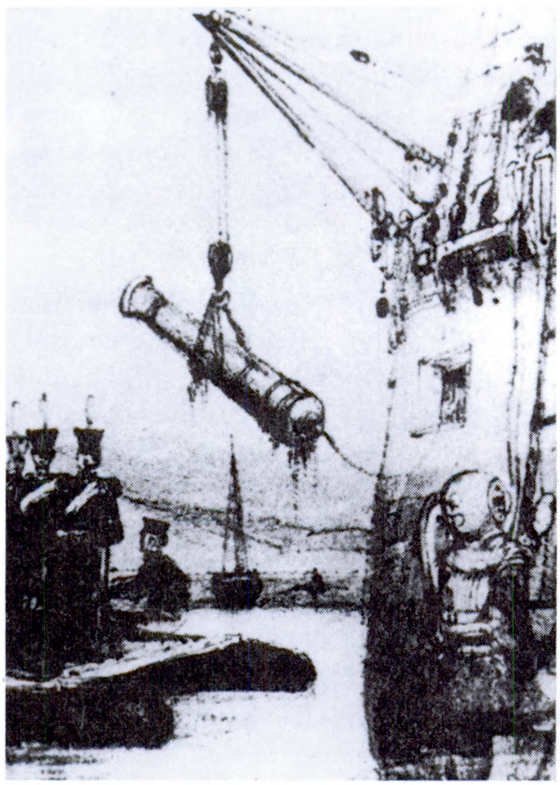


Figure 1-7. Salvaging valuable brass cannons from a sunken warship.

Credit for the development of the first practical diving dress has been given to Augustus Siebe (Figure 1-8). He was one of several men who produced a successful apparatus at the same time. Two salvage operators, John and Charles Deane, obtained patents in 1823 on the basic design for a smoke apparatus to permit firemen to move about in burning buildings (Figure 1-9). By 1828 this had evolved into Deanes' Patent Diving Dress, consisting of a heavy suit for protection from the cold, a helmet with viewing ports, and hose connections for delivering surface-supplied air. The helmet was not fastened to the suit, but simply rested on the diver's shoulders, held in place by its own weight and by straps to a waist belt. The exhausted or surplus air passed out from under the edge of the helmet and posed no problem as long as the diver was standing upright. However, should he trip and fall, the helmet could quickly fill with water. In 1836, the Deanes issued a diver's manual, perhaps the first ever produced.

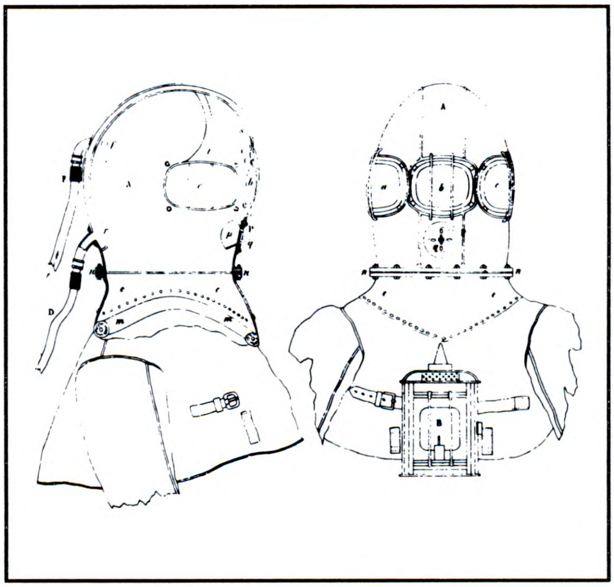


Figure 1-9. Deanes' Smoke Apparatus.

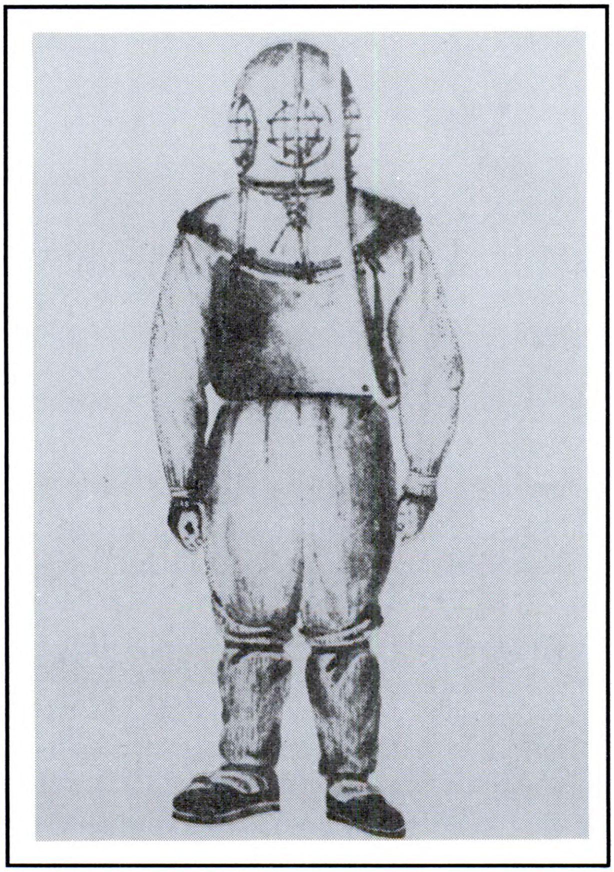


Figure 1-8. Siebe's First Enclosed Diving Dress and Helmet.

Augustus Siebe's initial contribution to diving was essentially a modification of the Deane outfit. Siebe sealed the helmet to the dress at the collar by using a short, waist-length waterproof suit, and added an exhaust valve to the system. Known as Siebe's Improved Diving Dress, this apparatus is the direct ancestor of the standard deep-sea diving dress MK V, which was replaced by the MK 12 Surface-Supplied Diving System in the early 1980's.

By 1840, several other types of diving dress had appeared on the scene and were being used in actual diving operations. At that time, a unit of the British Royal Engineers was engaged in the sizable project of removing the remains of the sunken warship, *HMS Royal George*. *HMS Royal George* was fouling a major fleet anchorage just outside of Portsmouth, England (Figure 1-10). Colonel William Pasley, the officer in charge, decided that his operation was an ideal opportunity to formally test and evaluate the various types of apparatus. He was wary of the Deane apparatus because of the possibility of helmet flooding and formally recommended

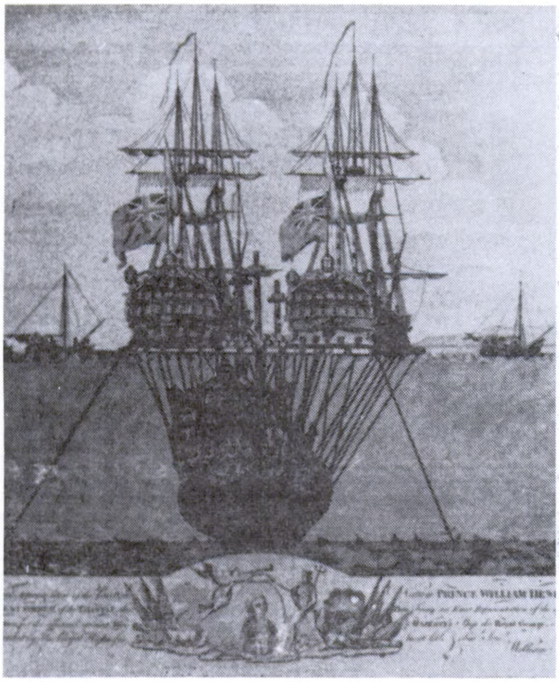


Figure 1-10. **The Salvage of the *HMS Royal George*.**

that the Siebe dress be adopted for any future operations.

When Colonel Pasley's project had been completed, an official government historian noted that "of the seasoned divers, not a man escaped the repeated attacks of rheumatism and cold." The divers had been working for six or seven hours a day, much of it spent at depths of 60 to 70 feet. Colonel Pasley and his men did not realize the implications of the observation. What appeared to be rheumatism was, in fact, a symptom of a far more serious physiological problem that, within a few years, was to become of great importance to the profession of diving.

1-2.3 The Mysterious Malady. At the same time that a practical diving dress was being perfected, other inventors were working to improve the diving bell by increasing its size and adding high-capacity air pumps capable of delivering sufficient pressure to keep water entirely out of the bell's interior. This improved pump capability soon led to the construction of chambers large enough to permit several men to engage in dry work on the bottom. This was particularly advantageous in projects such as excavation of bridge footings or the construction of tunnel sections where long periods of work were required. These dry chambers came to be known as caissons, a French word literally meaning "big boxes."

Caissons were designed to provide ready access from the surface. Through the use of an air-lock, the pressure inside could be maintained while men or materials could be passed in and out. The development of the caisson was a major step forward in engineering technology, and its use grew quickly (Figure 1-11).

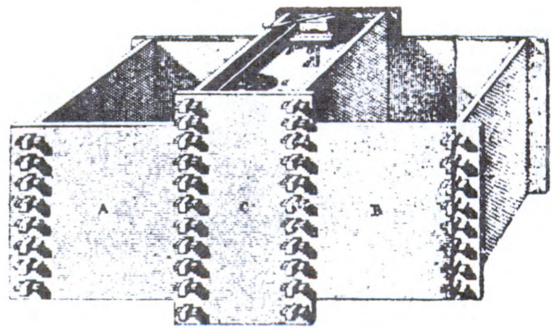


Figure 1-11. French Caisson. This caisson could be floated over the worksite and lowered to the bottom by flooding the side tanks.

With the expanding use of caissons, an apparently new and unexplained malady began to affect the caisson workers. After completing a shift and returning to the surface, the divers frequently would be struck by dizzy spells, difficulty in breathing, or by sharp pains in the joints or abdomen. The sufferer would usually recover after a period of time, but he might never be competely free of some of the symptoms. The caisson workers often noted that they felt better working on the job, but possibly attributed this to being rested at the beginning of a shift as opposed to being tired when the work day was over (when they always seemed to feel worse).

As caisson work was extended to ever larger projects and to greater operating pressures, the physiological problems increased in number and severity. Fatalities occurred with alarming frequency.

The malady was called, logically enough, caisson disease. However, workers on the Brooklyn Bridge project in New York gave the sickness a more descriptive name that has remained ever since: the bends. The term may have grown out of the similarity between the contorted posture of the suffering worker and an awkward, forward-leaning stance known as the Grecian bend, affected by fashionable ladies of the time.

Today the bends is the most well-known danger of diving. Although men had been diving for thousands of years, until the time of the caisson, few men had spent much time working under great atmospheric pressure. Those few individuals such as Pasley, who had experienced some aspect of the disease, were simply not prepared to look for anything more involved than indigestion, rheumatism, or arthritis.

The actual cause of caisson disease was first clinically described in 1878 by a French physiologist, Paul Bert. In his studies on the effect of pressure on human physiology, Bert determined that breathing air under pressure forced quantities of nitrogen into solution in the blood and tissues of the body. As long as the pressure remained, the gas was held in solution. When the pressure was quickly released, as when a worker left the caisson, the nitrogen returned to a gaseous state too rapidly to pass out of the body in a natural manner. Bubbles of the gas formed throughout the body, causing the wide range of symptoms associated with the disease. If the flow of blood to a vital organ was blocked by the bubbles, paralysis or death could occur.

Bert recommended that caisson workers gradually decompress and divers return to the surface slowly. His studies led to an immediate improvement for the caisson workers when they discovered their pain could be relieved merely by returning to the pressure of the caisson as soon as the symptom appeared. Within a few years, specifically-designed recompression chambers were being placed at job sites to provide a more controlled situation for handling the bends (Figure 1-12).

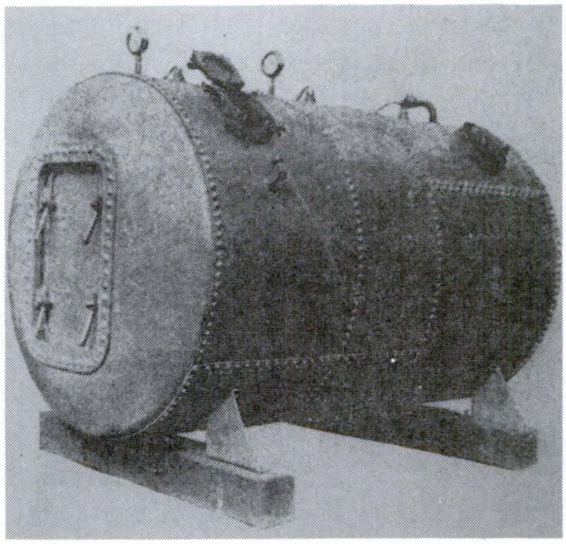


Figure 1-12. Early Double-Lock Recompression Chamber.

The pressure in the chambers could be increased or decreased as needed for an individual worker. One of the first successful uses of a recompression chamber was in 1879 during the construction of a tunnel between New York and New Jersey. This was the first attempt at a subway tunnel under the Hudson River. Use of the chamber markedly reduced the number of serious cases and fatalities caused by the bends.

1-2.4 Other Physiological Discoveries. Bert's recommendation that divers use a gradual but steady ascent was not a complete success, and some divers continued to suffer from the bends. There was a general feeling at the time that divers had reached the practical limits of the art and that 120 feet was about as deep as anyone could work. This was because of the repeated incidence of the bends from deeper dives, and because of a noted inefficiency on the part of the diver beyond that depth. Occasionally, divers would lose consciousness while working at 120 feet.

J.S. Haldane, an English physiologist, conducted experiments with Royal Navy divers from 1905 to 1907 and determined that part of the problem was due to a relatively simple fact: the divers were not adequately ventilating their helmets and high levels of carbon dioxide were accumulating. The problem was solved by establishing a standard supply rate of flow (1.5 cubic feet of air per minute, measured at the pressure of the diver), and by providing pumps of sufficient capacity to maintain the flow, ventilating the helmet on a continuous basis.

Haldane also composed a set of diving tables which established a stage method of decompression. Though they have been restudied and improved over the years, these tables remain the basis of the accepted method for bringing a diver to the surface.

An immediate result of Haldane's studies was an extension of the practical operating depth for air divers to slightly more than 200 feet. At the time, this limit was not imposed by physiological factors, but only by the capabilities of the hand-pumps available to provide the air supply.

It was not long before divers were moving into deeper water, and another unexplained malady began to appear. The diver would seemingly become intoxicated, sometimes feeling euphoric, and frequently lose his sense of judgment to the point of forgetting the purpose of the dive. In the 1930's this "rapture of the deep" was linked to nitrogen in the air breathed under higher pressures. Known as nitrogen narcosis, this condition occurs because nitrogen has anesthetic properties that become progressively more severe with increasing air pressure. To avoid the problem, special breathing mixtures such as helium-oxygen are now used instead of air for deep diving.

1-2.5 Armored Diving Suits. Numerous inventors, many having little or no experience underwater, worked to create an armored diving suit which would free the diver from any and all problems of pressure. In such a suit, he could breathe air at normal atmospheric pressure and descend to great depths without any ill effects. The barrel diving suit of John Lethbridge was essentially an armored suit with a limited operating depth (Figure 1-13).

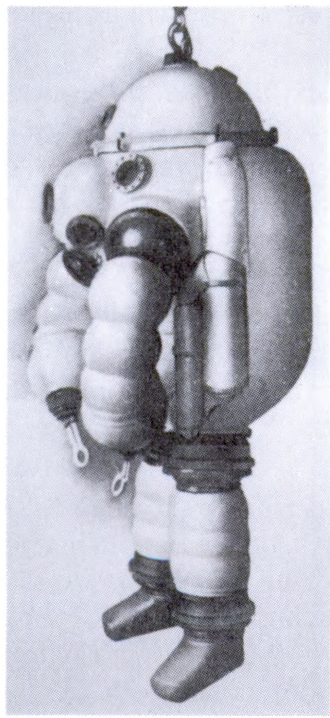


Figure 1-13. Armored Diving Suit.

The utility of most armored suits was questionable. They were too clumsy for the diver to be able to accomplish much work, and too complicated to provide protection from extreme pressure. The maximum anticipated depth of the various suits developed in the 1930s was 700 fsw, and was never reached in actual diving. New pursuits in the area of armored suits, now called one-atmosphere diving suits, have demonstrated their capability for specialized underwater tasks.

1-2.6 The MK V Deep-Sea Diving Dress. By 1905, the Bureau of Construction and Repair had designed the MK V Diving Helmet which seemed to address many of the problems encountered in diving (Figure 1-14).

Figure 1-14. MK V Deep-Sea Diving Dress.

The MK V, with its associated deep-sea dress and umbilical, was used for all submarine rescue and salvage work undertaken in peacetime, including the *USS S-51* and *USS S-4,* and practically all salvage work undertaken during World War II. The deep-sea outfit was designed for extensive, rugged diving work and provided the diver maximum physical protection and some maneuverability.

The 1905 MK V Diving Helmet had an elbow inlet with a safety valve that allowed air to enter the helmet, but not to escape back up the umbilical in the event of an interruption of the air supply. Air was expelled from the helmet through an exhaust valve on the right side, below the port. The exhaust valve was vented toward the rear of the helmet to prevent escaping bubbles from interferring with the diver's field of vision.

By 1916, several improvements had been made to the helmet including a rudimentary communications system via a telephone cable, and a regulating valve that was operated by an interior push button. The regulating valve allowed some control of the atmospheric pressure. Added to the left side of the helmet was a supplementary relief valve which became known as the spitcock. A safety catch was also incorporated to prevent the helmet from being detached accidentally from the breast plate. Further improvements to the exhaust valve and the communications were made by 1927, while at the same time a lessening of the weight of the helmet provided more comfort for the diver. Since 1927, the MK V had changed very little. It remained basically the same helmet used in salvage operations of the *USS S-51* and *USS S-4* in the mid-twenties. The MK V Diving Helmet became the standard U.S. Navy diving equipment until succeeded by the MK 12 Surface-Supplied Diving System (SSDS) in February 1980, when the first training classes for the MK 12 began.

1-2.7 Development of the Free Diver. Deane, Siebe, and the others had given man the ability to remain underwater for extended periods, with enough flexibility of movement to accomplish a significant amount of work during his stay. However, the diver was still tied to the surface. Without the vital umbilical of his air hose he could not survive, let alone function. The hose gave him life but limited his range of operation.

Inventors searched for methods to release the diver from the surface hose, looking for a system that would permit increased freedom of movement without increased hazards. The solution was obvious: provide the diver with his own portable air supply. Today the self-contained underwater breathing apparatus (SCUBA) is not only a reality, but has replaced the deep-sea diving outfit as the most frequently used type of diving gear. For many years, however, the SCUBA was only a theoretical possibility. Neither a pump (compressor) of sufficient capacity nor cylinders of adequate strength to handle the high pressures needed to provide a practical air supply existed.

Development of SCUBA took place gradually, and over the years three basic types evolved: open-circuit, closed-circuit, and semiclosed-circuit.

In the open-circuit apparatus, air is taken from a supply cylinder, inhaled, and the exhaust is vented directly to the surrounding water. The basic closed-circuit system uses a cylinder of 100 percent oxygen which supplies a breathing bag. The oxygen used by the diver is recirculated in the apparatus. It passes through a chemical filter which removes carbon dioxide, and additional oxygen is added from the tank to replace that which is consumed in breathing. For special warfare operations, the closed-circuit system (oxygen rebreather) has a major advantage over the open-circuit type. It does not produce a telltale trail of bubbles on the surface.

The third basic type, semiclosed apparatus, combines features of the other two systems. Using a mixture of gases for breathing, the apparatus recycles the gas through a carbon dioxide removal canister and continually adds a small amount of oxygen-rich mixed gas to the system from a supply cylinder. The supply gas flow is preset to satisfy the body's oxygen demand, and a part of the recirculating mixed-gas stream, equal to the supply gas flow, is continually exhausted to the water. Because the quantity of make-up gas is constant regardless of depth, the semiclosed SCUBA provides significantly greater endurance than open-circuit systems in deep diving.

Two main paths of development were followed: open-circuit and closed-circuit. The first and highly necessary component of an open-circuit apparatus was a demand regulator, designed early in 1866. Patented by Benoist Rouquayrol, the regulator adjusted the flow of air from the tank to meet the breathing and pressure requirements of the diver. However, since cylinders of sufficient strength to contain air at high pressure could not be built at the time, Rouquayrol adapted his regulator to surface-supplied diving equipment and the technology turned toward closed-circuit designs. The application of Rouquayrol's concept of a demand regulator to a successful open-circuit SCUBA was to wait more than 60 years.

In 1878, the first commercially practical self-contained breathing apparatus was developed by H.A. Fleuss. It was closed-circuit and used 100 percent oxygen for breathing. Because the system used only oxygen, the quantity of gas in the tank did not have to be as great as it would with compressed air (which is only about 21 percent oxygen). Thus, the need for high-strength tanks was eliminated.

Unfortunately, at the time of his invention, Fleuss was not aware of the serious problem of oxygen toxicity caused by breathing 100 percent oxygen under pressure. It was not until many years later that researchers determined the maximum safe depth for use of 100 percent oxygen.

Two years after its invention, the Fleuss SCUBA figured prominently in a highly publicized achievement by an English diver, Alexander Lambert. A tunnel under the Severn River had flooded in 1880 and Lambert, wearing a Fleuss apparatus, walked 1,000 feet along the tunnel, in complete darkness, to close several crucial valves.

As development of the closed-circuit design continued, the Fleuss equipment was improved by the addition of a demand regulator and tanks capable of holding oxygen at more than 2,000 psi. By World War I, the Fleuss SCUBA (with modifications) was the basis for submarine escape equipment used in the Royal Navy.

In 1933, the thread of open-circuit development was again picked-up when a French naval officer, Commander LePrieur, constructed an open-circuit SCUBA using a tank of compressed air. However, LePrieur did not include a demand regulator in his design and, the diver's main effort was diverted to the constant manual control of his air-supply. This fact, coupled with extremely short endurance, severely limited the practical use of LePrieur's apparatus. The main emphasis continued to focus on closed-circuit development.

Although closed-circuit equipment was restricted to shallow-water use and carried with it the potential danger of oxygen toxicity, its design soon reached a suitably high level of efficiency. By World War II, it was in wide use by navies on both sides of the conflict. British divers, working out of midget submarines, aided in the placement of explosive charges under the keel of the German battleship *Tirpitz* (Figure 1-15). Italian divers, using closed-circuit gear, rode chariot torpedoes fitted with seats and manual controls in repeated attacks against British shipping. In the final stages of the war, the Japanese employed an underwater equivalent of their kamikaze aerial attack: the kaiten diver-guided torpedo.

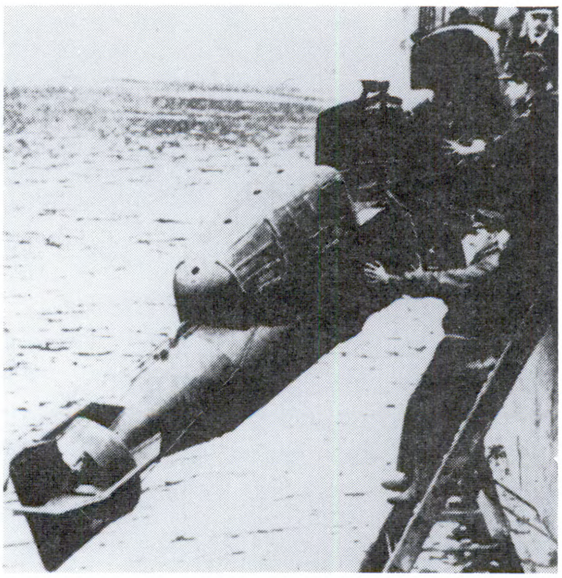


Figure 1-15. Midget Submarine Used During WW II.

The most recent innovation in closed-circuit systems employs a mixed gas for breathing and electronically senses and controls oxygen concentration. This type of apparatus retains the bubble-free characteristics of 100 percent oxygen recirculators while significantly improving depth capability.

At the same time that actual combat operations were being carried out with closed-circuit apparatus, two Frenchmen, one a naval officer and the other an engineer, achieved a significant breakthrough in open-circuit SCUBA design. Working in a small Mediterranean village under the difficult and restrictive conditions of German-occupied France, Captain Jacques-Yves Cousteau and Emile Gagnan combined an improved demand regulator and high-pressure air tanks to create the first truly efficient and safe open-circuit SCUBA. Cousteau and his companions brought the Aqua-Lung to a high state of development as they explored and photographed wrecks, developing new diving techniques and testing their equipment. Their work was the culmination of literally hundreds of years of progress, blending the work of Rouquayol, Fleuss, and LePrieur. Cousteau used his gear successfully to a depth of 180 fsw without significant difficulty and with the end of the war the Aqua-Lung quickly became a commercial success. Today this apparatus represents the most widely used of diving equipments, opening the underwater world to anyone with suitable training and the necessary physical abilities.

1-3 RECENT DEVELOPMENTS

The underwater freedom brought about by the development of SCUBA has led to a rapid growth of interest in diving. Sport diving is the popular aspect of this interest, but science and commerce have also benefited. Biologists, geologists, and archaeologists have all gone underwater, seeking new clues to the origins and behavior of the earth, man, and civilization as a whole. An entire industry based around commercial diving has flourished, with the major portion of activity in the area of offshore petroleum production.

During the post-war era, the art and science of diving progressed rapidly, with emphasis placed on improving existing diving techniques, creating new methods, and developing the necessary equipment to serve these methods.

A complete generation of new and sophisticated equipment took form, with substantial improvements being made in both open-and closed-circuit apparatus. However, the most significant aspect of this technological expansion has been the closely-linked development of saturation diving techniques and deep diving systems.

1-3.1 Saturation Diving. As divers dove deeper and attempted more ambitious underwater tasks, the need for a safe method of extending actual working time at depth became evident.

In virtually any deep diving operation, decompression is the most time-consuming factor. For example, if a diver were to work for an hour at a depth of 200 fsw, he would then be required to spend an additional three hours and twenty minutes in the water undergoing the necessary decompression. The time required to permit dissolved gases to come out of solution and leave the diver's body increases markedly with the depth and duration of the dive.

However, there is a point beyond which the diver does not need additional decompression: the point at which he becomes saturated with the gases which make decompression necessary. Once his blood and tissues have absorbed all the gas they can hold at that depth, the time required for decompression becomes constant. As long as the depth is not increased, additional time on the bottom is free of any additional decompression.

If a diver had the means to remain under pressure for the entire period of his required task, whether it be days or weeks, he would face a lengthy decompression upon completion of the project. For a 40-hour task at 200 fsw, a diver, if saturated, would spend five days at bottom pressure and two days in decompression as opposed to a total of 40 working days of single dives and lengthy decompression periods using conventional methods.

The theory of saturation diving began with the idea that there needed to be a method for lengthening a diver's bottom time. In a meeting between then Commander George F. Bond, U.S. Navy and Captain Jacques-Yves Cousteau in 1957, it was decided that the necessary data to prove the theory of saturation diving could be developed at the U.S. Navy Submarine Medical Center at New London where Dr. Bond was Officer-in-Charge. With the support of the U.S. Navy, Dr. Bond initiated the Genesis project to test the theory of saturation diving.

Using laboratory animals, goats and eventually Navy divers, Dr. Bond was able to establish that the theory of saturation was in fact a safe and accepted method of long term exposures on the ocean floor. With the loss of the submarine *USS Thresher* the navy was interested in knowing what saturation diving had to offer in deeper submarine rescue and salvage. This existing interest helped pave the way for further studies in this new concept. Project Genesis proved that men could sustain themselves for long periods under pressure and what was then needed was a means to put this concept to use on the ocean floor.

At this point, the Office of Naval Research, the Navy Mine Defense Laboratory and Dr. Bond's small staff of volunteers gathered in Panama

City, Florida, where construction and testing of the *Sealab I* habitat began in December 1963.

During this same time period, Edwin A. Link (an American inventor known for his Link Trainer which simulates cockpit experience in the training of aviators), and Jacques-Yves Cousteau began deep ocean tests.

In September of 1962, Link sent a Swiss diver to a depth of 200 fsw for 24 hours in a specially designed diving system. Four days later, Cousteau placed two men in a gas-filled, pressure-balanced underwater habitat at 33 fsw where they stayed for 169 hours, moving freely in and out of their deep-house. The following summer, six of Cousteau's men spent a month underwater at 36 fsw, with two men spending a week in a deeper chamber at 90 fsw. These divers made excursions to a depth of 330 fsw.

In 1964, Link expanded his work by putting two men at 432 fsw in a habitat for two days and nights. Almost simultaneously, Captain Bond headed the U.S. Navy's first experiment in *Sealab I*. Working off Bermuda, Bond placed four divers at 192 fsw for nine days, eventually raising their habitat to 81 fsw where they transferred to a decompression chamber that was then hoisted aboard a four legged offshore support structure.

Sealab II, (Figure 1-16), which took place a year later, put three teams of ten men each in a habitat at 205 fsw, with each team spending 15 days at depth and one man remaining for 30 days.

All of these experiments in saturation technique required substantial surface support as well as extensive underwater equipment. However, a new type of system was soon to be developed that essentially eliminated any requirement for a diver to remain in the sea except for the actual time spent on a given task.

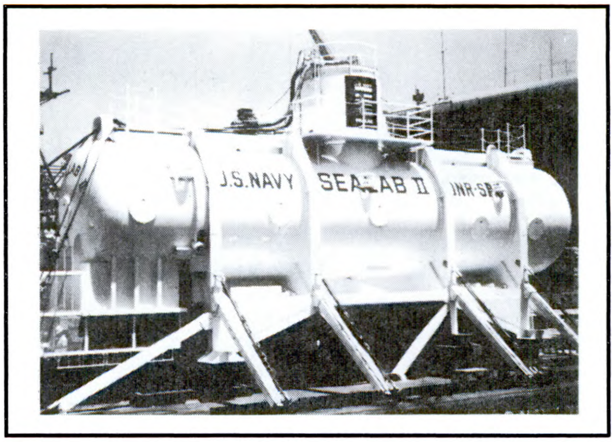


Figure 1-16. *Sealab II* Habitat.

1-3.2 Deep Diving Systems. Developed over the last twenty-five years, Deep Diving Systems (DDS) represent a substantial improvement over any previous methods of accomplishing deep undersea work. The DDS is readily adaptable to saturation techniques and provides a safe mechanism for maintaining the saturated diver under pressure in a dry environment. Whether employed for saturation or non-saturation diving, the Deep Diving System totally eliminates the need for long periods of decompression in the water where the diver is subjected to extended environmental stress. Additional benefits derived from use of the DDS include eliminating the need for underwater habitats and increasing operational flexibility for the surface-support ship.

The system consists of a Deck Decompression Chamber (DDC) mounted on a surface-support ship, and a Personnel Transfer Capsule (PTC) mated to the DDC (Figure 1-17). This combination is pressurized to a storage depth. In an operation, two or more divers enter the PTC. The PTC is unmated and lowered to the working depth, the interior of the capsule is pressurized to equal the pressure at depth, a hatch is opened, and one or more men swim out to accomplish their work. The diver can use a self-contained breathing apparatus with a safety tether to the capsule, or employ a mask and an umbilical that provides breathing gas and communications.

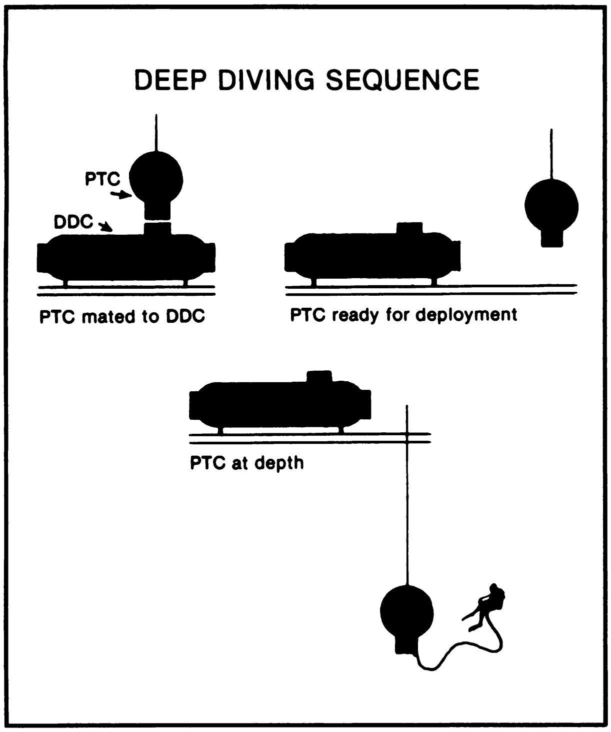


Figure 1-17. Operating Sequence of a Deep Diving System.

Once his task is finished, the diver enters the capsule, closes the hatch and returns to the support ship with the interior of the PTC still at the working pressure. The capsule is hoisted aboard, mated to the pressurized DDC, and the divers enter the larger, more comfortable DDC via an entry lock. The men remain in the DDC eating and resting until they must return to the undersea job site. Decompression is carried out comfortably and safely on the support ship.

1-4 DIVING IN THE U.S. NAVY

The U.S. Navy is the forerunner in the development of modern diving and underwater operations. The general requirements of national defense and the specific requirements of underwater reconnaissance, demolition, ordnance disposal, construction, ship maintenance, search, rescue, and salvage operations repeatedly give impetus to training and development.

1-4.1 Early History of U.S. Navy Diving.

The early history of diving in the U.S. Navy parallels that of the other navies of the world. Since the middle of the nineteenth century, the Navy has employed divers in salvage and repair of ships, in construction work, and in military operations.

For the most part, early Navy divers were swimmers and skin divers, with techniques and missions unchanged since the days of Alexander the Great. During the Civil War Battle of Mobile Bay, swimmers were sent in ahead of Admiral Farragut's ships to locate and disarm Confederate mines that had been planted to block the entrance to the bay.

In 1898, Navy divers were briefly involved in an international crisis when the *USS Maine* was sunk by a mysterious explosion while anchored in the harbor at Havana, Cuba. Navy divers were sent from Key West to study and report on the wreck. Although a Court of Inquiry was convened, the reason for the sinking was not found.

The beginning of the twentieth century saw the attention of all major navies turning towards developing a weapon of immense potential - the military submarine. The highly effective use of the new weapon by the German Navy in World War I heightened this interest, and an emphasis was placed on the submarine that continues today.

The U.S. Navy had operated submarines on a limited basis for several years prior to 1900. As American technology expanded, the U.S. submarine fleet grew rapidly. However, throughout the period of 1912-1939, the development of the Navy's F, H, and S class boats was marred by a series of accidents, collisions, and sinkings. Several of these submarine disasters resulted in a correspondingly rapid growth in the Navy diving capability.

Until 1912, U.S. Navy divers rarely went below 60 fsw. In that year, Chief Gunner George D. Stillson set up a program to test Haldane's diving tables and methods of stage decompression. A companion goal of the program was to develop improvements in Navy diving equipment. Throughout a three-year period, first diving in tanks ashore and then in open water in Long Island Sound from the *USS Walkie,* the Navy divers went progressively deeper, eventually reaching 274 fsw.

The experience gained in Stillson's program was put to dramatic use six months later when the submarine *USS F-4* sank near Honolulu, Hawaii. Twenty-one men lost their lives in the accident and the Navy lost its first boat in 15 years of submarine operations. Navy divers salvaged the submarine and recovered the bodies of the crew. The salvage effort incorporated many new techniques, such as the use of lifting pontoons, but what was most remarkable was that the divers completed a major salvage effort working at the extreme depth of 304 fsw, using air as a breathing mixture. These dives remain the record for the use of standard deep-sea diving dress. Because of the depth and the necessary decompression, each diver could remain on the bottom for only ten minutes. Even for such a limited time, the men found it hard to concentrate on the job at hand. They were unknowingly affected by nitrogen narcosis.

The publication of the first U.S. Navy Diving Manual and the establishment of a Navy Diving School at Newport, Rhode Island were the direct outgrowth of experience gained in the test program and the *USS F-4* salvage. When the United States entered World War I, the staff and graduates of the school were sent to Europe, where they conducted various salvage operations along the French coast.

The physiological problems encountered in the salvage of the *USS F-4* clearly demonstrated the limitations of breathing air during deep dives. Continuing concern that submarine rescue and salvage would be required at great depth focused Navy attention on the need for a new diver breathing medium. In 1924, the Navy joined with the Bureau of Mines in the experimental use of helium-oxygen mixtures. The preliminary work was conducted at the Bureau of Mines Experimental Station in Pittsburgh, Pennsylvania. 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 decompression time was shortened. This early work laid the foundation for development of reliable decompression tables and specialized apparatus, which are the cornerstones of modern deep diving technology.

One year later, in September of 1925, another submarine, the *USS S-51*, was rammed by a passenger liner and sunk in 132 fsw off Block Island, Massachusetts. Public pressure to raise the submarine and recover the bodies of the crew was intense. Navy diving was put in sharp focus and the Navy realized it had only 20 divers who were qualified to go deeper than 90 fsw. Diver training programs had been cut at the end of World War I, and the school had not been reinstituted.

Salvage of the *USS S-51* covered a ten month span of difficult and hazardous diving, and a special diver training course was made part of the operation. The submarine was finally raised and towed to the Brooklyn Navy Yard in New York.

Interest in diving was high once again and the Naval School, Diving and Salvage, was reestablished at the Washington Navy Yard in 1927. At the same time, the Navy brought together its existing diving technology and experimental work by shifting the Experimental Diving Unit (EDU), which had been working with the Bureau of Mines in Pennsylvania, to the Navy Yard as well.

Figure 1-18. Control Room of the Ocean Simulation Facility. This hyperbaric complex, at the Navy Experimental Diving Unit (NEDU) now located in Panama City, Florida, is capable of simulating most conditions experienced in open-water dives.

In the following years, EDU developed the U.S. Navy Air Decompression Tables, which have become the accepted world standard, and continued developmental work in helium-oxygen breathing mixtures for deeper diving.

The loss of the *USS F-4* and *USS S-51* provided the impetus for expanding the Navy's diving ability. However, the Navy's inability to rescue men trapped in a disabled submarine was not confronted until another major submarine disaster occured.

In 1927, the Navy lost the submarine *USS S-4* in a collision with the Coast Guard cutter *USS Paulding*. The first divers to reach the submarine in 102 fsw, 22 hours after the sinking, exchanged signals with the men trapped inside. The submarine had a hull fitting designed to take an air hose from the surface, but what had looked feasible in theory proved too difficult in reality. With stormy seas causing repeated delays, the divers could not make the hose connection until it was too late. All of the men aboard the *USS S-4* had died. Even had the hose connection been made in time, rescuing the crew would have posed a significant problem.

The *USS S-4* was salvaged after a major effort, and the fate of the crew spurred several efforts toward preventing a similar disaster. LT C.B. Momsen, a submarine officer, developed the escape lung which bears his name. It was given its first operational test in 1929 when 26 officers and men successfully surfaced from an intentionally bottomed submarine.

The Navy pushed for development of a rescue chamber that was essentially a diving bell with special fittings for connection to a submarine deck hatch. The apparatus, called the McCann-Erickson Rescue Chamber (Figure 1-19), was proven in 1939 when a submarine sank in 243 fsw. The *USS Squalus* carried a crew of 50. The rescue chamber made four trips and safely brought 33 men to the surface. The rest of the crew, trapped in the flooded after-section of the submarine, had perished in the sinking. The *USS Squalus* was raised by salvage divers using air and helium-oxygen mixtures (Figure 1-20). Following renovation, the submarine, renamed *USS Sailfish,* compiled a proud record in World War II.

1-4.2 World War II. Navy divers were plunged into the war with the Japanese raid on Pearl Harbor. The raid began at 0755, 7 December 1941; by 0915 that same morning, the first salvage teams were cutting through the hull of the overturned battleship *USS Oklahoma* to rescue trapped sailors. Teams of divers were put to work recovering ammunition from the magazines of sunken ships, to be ready in the event of a second attack.

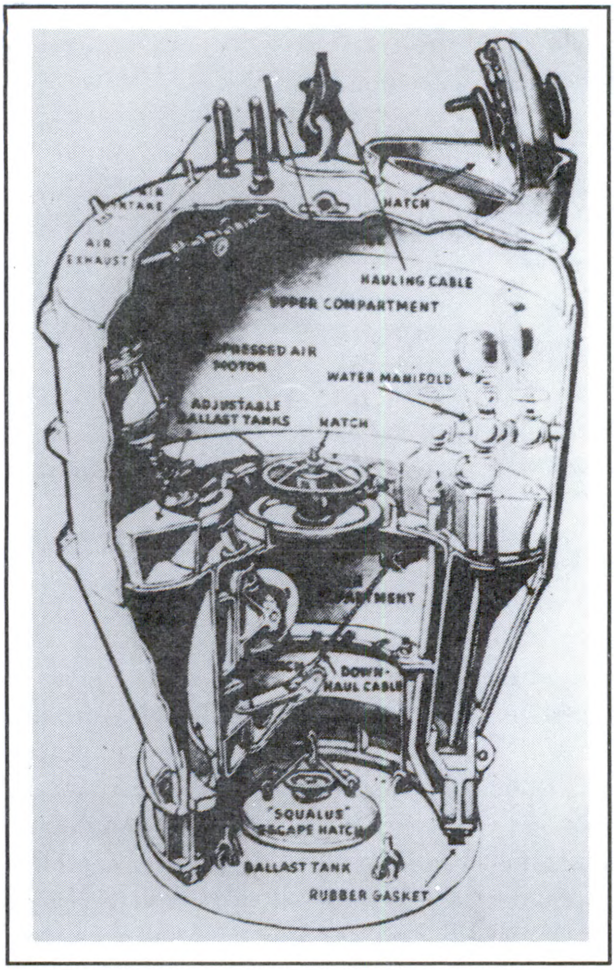


Figure 1-19. Vertical Section of the McCann-Erickson Rescue Chamber.

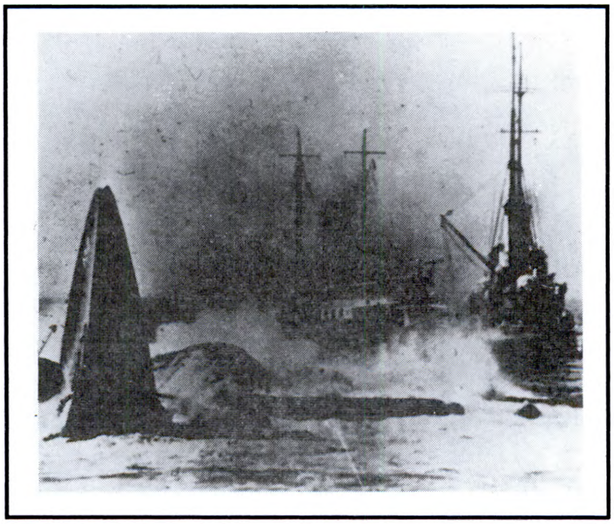


Figure 1-20. Salvage of the *USS Squalus*.

The immense salvage effort that followed at Pearl Harbor was highly successful (Figure 1-21). There were 101 ships in the harbor at the time of the attack and most sustained damage. The hardest hit were the battleships, being one of the primary targets of the raid. Six battleships were sunk and one was heavily damaged. Four of these were salvaged and returned to the fleet for combat duty; the *USS Oklahoma* was righted and refloated but sank en route to a shipyard in the United States. Only the USS Arizona and the former battleship USS Utah could not be salvaged.

Figure 1-21. U.S. Navy Salvage Operation at Pearl Harbor.

Battleships were not the only subjects of the salvage effort. Throughout 1942 and part of 1943, Navy divers worked on destroyers, supply ships, and other badly needed vessels, often using makeshift shallow water apparatus inside water and gas-filled compartments. In the course of the Pearl Harbor effort, Navy divers spent 16,000 hours underwater during 4,000 dives. Contract civilian divers contributed another 4,000 diving hours.

While divers in the Pacific were hard at work at Pearl Harbor, a major challenge was presented to the divers on the East Coast. The interned French passenger liner *Normandie* (rechristened as the *USS Lafayette*) caught fire alongside New York City's Pier 88. Losing stability from the tons of water poured on the fire, the ship capsized at her berth.

To clear the vitally needed pier, the ship had to be salvaged. The Navy took advantage of this unique opportunity for training by using the New York site for a new diving and salvage school. The Naval Training School (Salvage) was established there in September 1942, and was transferred to Bayonne, N. J. in 1946.

Salvage operations were not, of course, the only missions assigned to Navy divers during the war. Many dives were made to inspect sunken enemy ships and to recover materials such as code books or other intelligence items. One Japanese cruiser yielded not only $500,000 in yen, but also provided valuable information concerning plans for the defense of Japan against the anticipated Allied invasion.

1-4.3 Combat Swimmers. The combat diving mission was the same in World War II as it had been in previous wars: to remove obstacles from enemy waters and to gather intelligence. The Navy's Underwater Demolition Teams (UDT) (Figure 1-22), were created when bomb disposal experts and SeaBees (combat engineers) teamed together in 1943 to devise methods for removing obstacles that the Germans were placing off the beaches of France.

The first UDT combat mission, however, was in the Pacific. It was a daylight reconnaissance and demolition project off the beaches of Saipan in June, 1944. In March of the next year, preparing for the invasion of Okinawa, one underwater demolition team achieved the exceptional record of removing 1,200 underwater obstacles in two days, under heavy fire, without a single casualty.

Diving apparatus was not extensively used by the UDT during the war. No suitable equipment

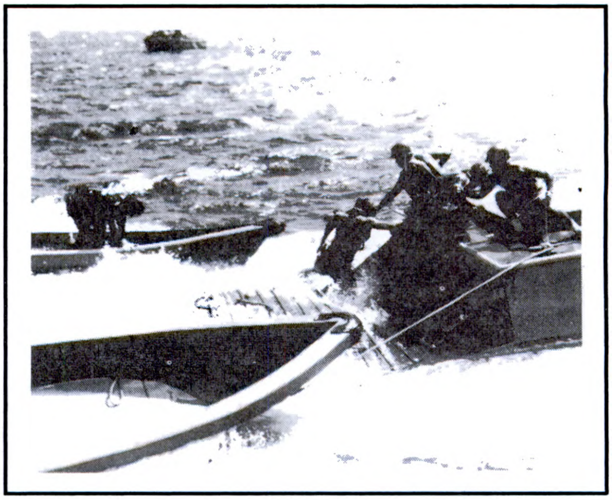


Figure 1-22. Deployment and Recovery of Navy UDT Frogmen.

was readily available. UDT experimented with a modified Momsen lung and other types of breathing apparatus, but not until 1947 did the Navy's acquistion of Aqua-Lung equipment give impetus to the diving aspect of UDT operations. The trail of bubbles from the open-circuit apparatus limited the type of mission in which it could be employed, but a special SCUBA platoon of UDT members was formed to test the equipment and determine appropriate uses for it.

Through the years since, the mission and importance of the UDT has grown. In the Korean Conflict, during the period of strategic withdrawal, the UDT destroyed an entire port complex to keep it from the enemy.

Today Navy combat swimmers are organized into two separate groups, each with specialized training and missions. The Explosive Ordnance Disposal (EOD) team has the mission of handling, defusing, and disposing of munitions and other explosives. The Sea, Air, and Land (SEAL) special warfare teams make up the second group of Navy combat swimmers. SEAL team members are trained to operate in all of these environments. They qualify as parachutists, learn to handle a range of weapons, receive intensive training in hand-to-hand combat, and are expert in SCUBA and other swimming and diving techniques. In Vietnam, SEALs were deployed in special counterinsurgency and guerrilla warfare operations (Figure 1-23). The SEALs also participated in the space program by securing flotation collars to returned space capsules and assisting astronauts during the helicopter pickup (Figure 1-24).

Figure 1-23. Beach Landing by a SEAL Team Det .

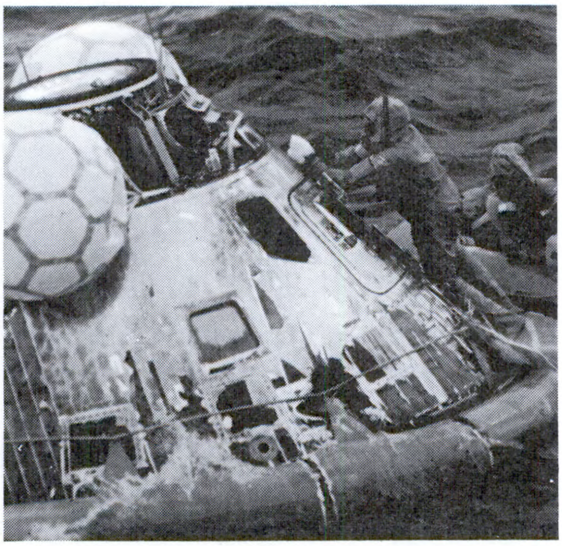


Figure 1-24. SEAL Divers assisting in the recovery of the crew of *Apollo II*.

1-4.4 Fleet Diving Since World War II. Navy diving has not been limited to tactical combat operations, wartime salvage, and submarine sinkings. Fleet diving has become increasingly important and diversified since World War II. A major part of the diving mission is the inspection and repair of naval vessels to minimize downtime and the need for drydocking. Other aspects of fleet diving include the recovery of practice and research torpedoes, installation and repair of underwater electronic arrays, underwater construction, and location and recovery of downed aircraft. Ship sinkings and beachings caused by storm damage and human error continue to demand the fleet's salvage and harbor clearance capabilities in peacetime as well as in times of hostilities.

1-4.5 Loss of the *USS Thresher*. Just as the loss of the *USS F-4, USS S-51, USS S-4* and the sinking of the *USS Squalus* caused an increased concern in Navy diving in the 1920s and 1930s, a submarine disaster of major proportions had a profound effect on the development of new diving equipment and techniques in the postwar period. This was the loss of the nuclear attack submarine *USS Thresher* and all her crew in April, 1963. The submarine sank in 8,400 fsw, a depth beyond the survival limit of the hull and far beyond the capability of any existing rescue apparatus.

An extensive search was initiated to locate the submarine, and if possible, determine the cause of the sinking. The first signs of the *USS Thresher* were located and photographed a month after the disaster. Collection of debris and photographic coverage of the wreck continued for about a year.

Two special study groups were formed as a result of the sinking. The first was a Court of Inquiry, which attributed probable cause to a piping system failure. The second, the Deep Submergence Review Group (DSRG), was formed to assess the Navy's undersea capabilities. Four general areas were examined: search, rescue, recovery of small and large objects, and the Man- In-The-Sea concept. The basic recommendations of the DSRG called for a vast effort to improve the Navy's capabilities in these four areas.

1-4.6 Deep Submergence Systems Project. Direct action on the recommendations of the DSRG came with the formation of the Deep Submergence Systems Project (DSSP) in 1964, and an expanded interest regarding diving and undersea activity throughout the naval service.

Submarine rescue capabilities have been substantially improved with the development of the Deep Submergence Rescue Vehicle (DSRV) which became operational in 1972. This deep-diving craft is air-transportable, highly instrumented, and capable of rescue to a depth of 5,000 fsw.

Three additional significant areas of achievement for the Deep Submergence Systems Project have been that of Saturation Diving, the development of Deep Diving Systems, and progress in advanced diving equipment design.

1-4.7 U.S. Navy Saturation Diving. The U.S. Navy has developed and proved saturation diving techniques in its Sealab series (previously described in this chapter) as well as in on-going programs of research and development at the Navy Experimental Diving Unit (NEDU), Naval Medical Research Institute (NMRI), and the Navy Submarine Medical Research Laboratory (NSMRL) as well as many institutional and commercial hyperbaric facilities. In addition, saturation diving using Deep Diving Systems (DDS) is now a proven capability.

The Navy developed two types of DDS. The DDS MK 1 supported two 2-man teams of divers through a 14 day mission profile. The DDS MK 1 system used in trial dives to 1,148 fsw is no longer in service. The DDS MK 2 MOD 1, designed for saturation diving, supports two 4-man teams for an extended mission time. DDS MK 2 is installed as part of the basic equipment of the ASR 21 class of submarine rescue ships (Figure 1-25).

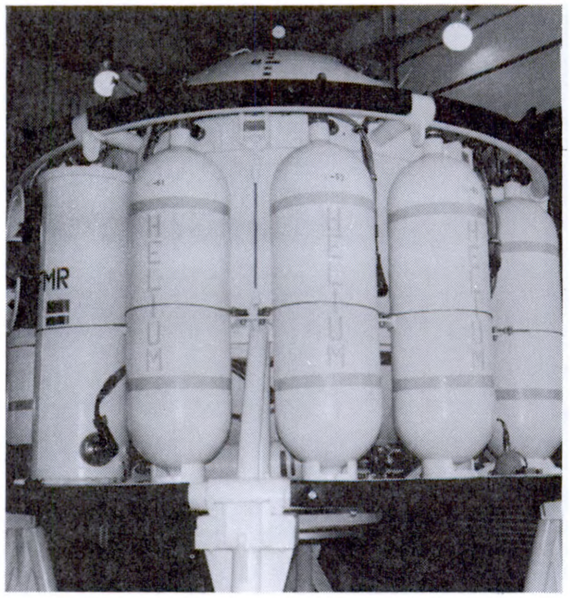


Figure 1-25. Deep Diving System Personnel Transfer Capsule (PTC).

1-4.8 Open-Sea Deep Diving Records. Diving records have been set and broken with increasing regularity in the past 70 years. In 1915 the 300-fsw mark was exceeded when three U.S. Navy divers, F. Crilley, W.F. Loughman, and F.C. Nielson, reached 304 fsw using the MK V dress. In 1972 the MK 2 Mod 0 DDS set the in-water record of 1,010 fsw which was subsequently broken in 1975 when divers using the MK 1 Deep Dive System descended to 1,148 fsw. A French dive team subsequently broke the open-sea record in 1977 with a depth of 1,643 fsw.

1-4.9 Deepest Salvage. The deepest salvage operation made with divers was 803 fsw, in 1981, when British divers retrieved 431 gold ingots from the wreck of *HMS Edinburgh*, sunk during World War II.

1-5 SUMMARY

Throughout the evolution of diving, from the earliest breath-holding sponge diver to the modern saturation diver, the basic reasons for diving have not changed. The needs of national defense, commerce, and science continue to provide the underlying basis for the development of diving. What has changed, and continues to change radically, is diving technology.

Each man who prepares for a dive has the opportunity and obligation to take with him the knowledge of his predecessors that was gained through difficult and dangerous experience. The modern diver must have a broad understanding of the physical properties of the undersea environment. He must have a detailed knowledge of his own physiology and how it is affected by the environment. The diver must learn to adapt to environmental conditions so that he can successfully carry out his mission.

Much of the diver's practical education will come from experience. However, before he can gain this experience, he must build a basic foundation from certain principles of physics, chemistry, and physiology and he must understand the application of these principles to the profession of diving.

The information required to build this foundation, as well as specific details concerning U.S. Navy operational methods and equipment, are the subject of the following chapters of this manual.

For a more comprehensive history of developments in mixed-gas and saturation diving technology see Chapter Nine, Volume Two, *U.S. Navy Diving Manual.*

CHAPTER TWO

UNDERWATER PHYSICS

2-1 INTRODUCTION

People readily function within the narrow atmospheric envelope present at the earth's surface and we seldom concern ourselves with survival requirements. However, once outside the boundaries of the envelope, the environment is hostile and our existence depends on our ability to counteract threatening forces. If divers are to function safely, we must understand the characteristics of the subsea environment and the techniques we can use to modify its effects. To accomplish this, we must have a basic knowledge of physics: the science of matter and energy and their interactions.

2-2 THE PHYSICAL WORLD

Matter and energy form the foundation of underwater physics. Of particular importance to a diver are the behavior of gases, the principles of buoyancy, and the properties of heat, light, and sound underwater.

2-2.1 Matter. Matter is defined as anything that occupies space and has mass. Matter possesses inertia. This means that energy is required to cause matter to change course or speed. Matter is the building block of the physical world. It is the physical makeup of the diver and the surrounding environment. The diver's air supply and everything else that supports him is composed of matter.

Scientists have identified more than 100 separate varieties of matter, known as elements, that make up the physical universe. An element is the simplest form of matter which exhibits distinct physical and chemical properties, and cannot be broken down by chemical means into other, more basic forms.

Elements are made up of atoms. Atoms are so infinitesimally small that it would take more than a million of them, laid side by side, to match the thickness of this page. The atom is the smallest particle of matter that carries the specific properties of an element. Elements combine to form the more than four million substances known to man.

Atoms group together to form molecules. Molecules usually exhibit properties different from any of the contributing atoms. For example, when two hydrogen atoms combine with one oxygen atom, a new substance, water, is formed (Figure 2-1).

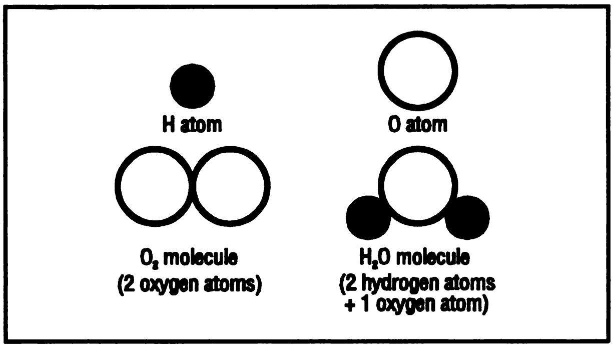


Figure 2-1. Molecules. Two similar oxygen atoms combine to form an oxygen molecule while the atoms of two different elements, hydrogen and oxygen, combine to form a water molecule.

Some molecules are active and try to combine with many of the other molecules that surround them. Other molecules are inert, and do not naturally combine with other substances. The presence of inert elements in breathing mixtures is of particular importance in diving, as will be shown later in the discussion of gas laws.

2-2.1.1 The Three States of Matter. Any element or substance produced by the joining of atoms can exist in one of three natural states: solid, liquid, or gas.

A solid has definite shape, weight, and volume. Liquids have definite volume and weight, but they take the shape of their containers. Gases have definite weight and occupy space, but lack definite volume or shape (Figure 2-2). A gas will expand to fill a container or, if completely unconfined, will spread continuously through the atmosphere. Gases and liquids are collectively referred to as fluids.

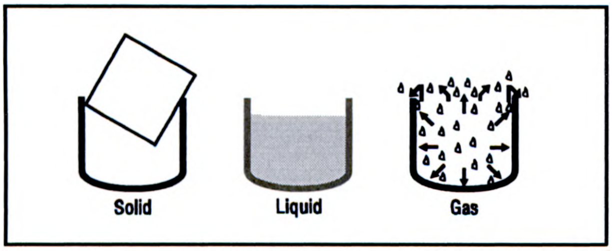


Figure 2-2. The Three States of Matter.

Whether a particular substance is a solid, liquid, or gas depends primarily upon temperature and partially upon pressure. In the solid state, coolest of the three, the molecules are rigidly aligned in essentially fixed patterns. They do move, but their motion is like a constant vibration. As temperature increases, the molecules increase their motion, slip apart from each other, and move around; the solid becomes a liquid. Further increases in temperature cause more molecular motion. As heat is added, a few of the molecules will spontaneously leave the surface of the liquid and become a gas. By the time the boiling point of the substance is reached, the molecules are moving very rapidly in all directions. When this happens, the liquid is quickly transformed into a gas.

Lowering the temperature reverses the sequence. As the gas molecules cool, their motion is reduced. The gas condenses and becomes a liquid. When the temperature falls, the liquid reaches the freezing point and returns to the solid state, completing the cycle.

2-2.2 Energy. The concepts of work and energy are closely interrelated and constitute the second major factor in the physical world. Work is defined as the application of a force through a distance. It is a force measured in pounds or kilograms which lifts, pulls, or pushes an object through a specific distance. Work may be applied in numerous ways, such as propelling an automobile and creating atomic particles. The rate at which work is performed is referred to as power.

2-2.2.1 Definition of Energy. Energy is the capacity to do work. The Law of the Conservation of Energy, formulated in the 1840's, states that energy in the universe can neither be created nor destroyed. Energy can be changed, however, from one form to another as seen in Figure 2-3.

The six basic forms of energy are: mechanical, heat, light, chemical, electrical, and nuclear.

Mechanical energy is possessed by an object as a result of its position or condition. When a body is held so that, if released, it can perform work, it possesses potential energy. An example is an automobile parked on a hill with its brakes set. Its mechanical energy is stored and referred to as potential energy. When a body is moving, it possesses energy of motion or kinetic energy. An example is an automobile which is rolling down a steep hill. While in motion it has kinetic energy.

Heat is energy possessed by a substance as a result of the motion of the substance's molecules. Heat added to a substance results in increased molecular motion and an associated rise in its temperature. A common example of heat energy is the boiling of water over an open flame.

Light is energy in the form of waves of electromagnetic radiation. Light energy from the sun provides the sustenance for green plants upon which most animal life, including man, depends for food.

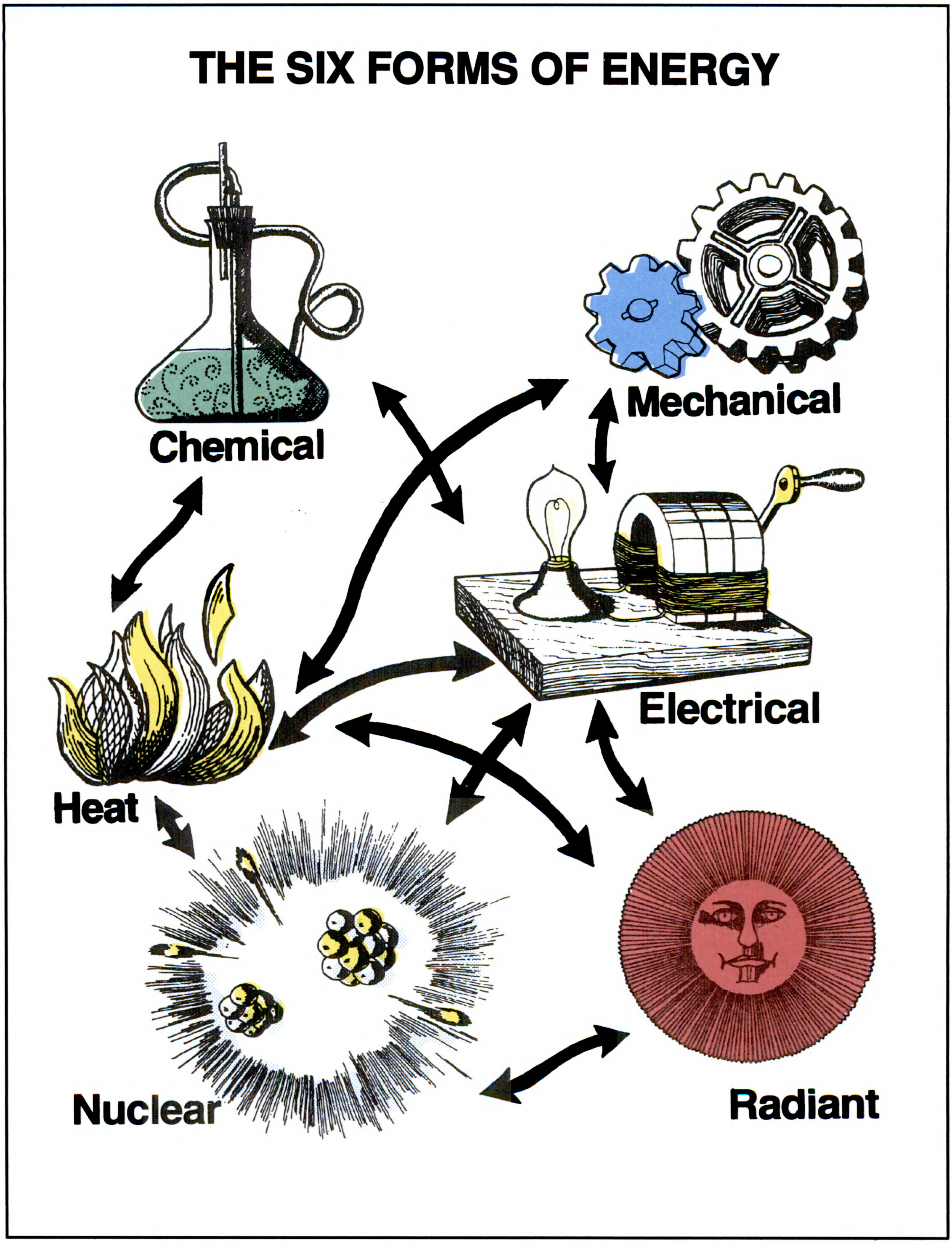


Figure 2-3. The Six Forms of Energy.

Chemical energy is stored within matter as a result of its molecular formation. Common examples of chemical energy are coal, oil, and gas. Their energies are released in the form of heat during combustion.

Electrical energy is created by the interaction of electrons (negative particles) and protons (positive particles). A battery is a source of stored (potential) electrical energy.

Nuclear or atomic energy is the force that holds the fundamental particles of the nucleus of atoms together. A nuclear power plant functions by the breakdown of heavy nuclei into lighter nuclei (fission) with an associated release of vast quantities of heat energy in a controlled manner to generate steam. Fusion is the joining of two lighter nuclei to form a heavier nucleus.

The complete subject of energy - its measurement, transformations, and uses - is a vast and complex aspect of physics beyond the scope of this manual. Consequently, only those aspects of energy having special importance in diving because of their unusual effects underwater are discussed in this chapter. Among these are the principles of light, heat, and sound.

2-3 UNITS OF MEASUREMENT

Physics relies heavily upon standards of comparison of one state of matter or energy to another. Understanding and applying the principles of physics requires that divers be able to employ a variety of units of measurement.

Two systems of measurement of force, length, and time are in wide use throughout the world. They are the English System and the Metric System. The English System, based upon the pound, foot, and second, is commonly used in the United States, but is being replaced throughout the rest of the world with the Metric System. The Metric System, originally developed in continental Europe, employs the kilogram, meter, and second as fundamental units of measure. The Metric System is so widely used, particularly in scientific work, that a diver sooner or later will come in contact with it. 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 English System. Conversion from one system to another may be readily accomplished using the conversion factors in Appendix C.

2-3.1 Length. The principal metric unit of length is the meter (39.37 inches). Smaller lengths are measured in millimeters (mm) or centimeters (cm). Greater lengths are measured in kilometers (km).

Example: Convert one meter to centimeters.

Solution: Step 1. Move the decimal point two places to the right.

$$1.00\ meter = 100.\ centimeters$$

Example: Convert one meter to millimeters.

Solution: Step 1. Move the decimal point three places to the right.

$$1.000\ meter = 1000.\ millimeters$$

Example: Convert 10 feet to meters.

Solution: Step 1.

$$\frac{10\ feet}{3.28\ feet/meter} = 3.04\ meters$$

Example: Convert 10 meters to feet.

Solution: Step 1.

$10\ meters \times 3.28\ feet/meter = 32.8\ feet$

Example: Convert one kilometer to meters.

Solution: Step 1. Move the decimal point three places to the right.

$1.0\ kilometer = 1000.\ meters$

2-3.2 Area. The Metric System uses length squared to measure area, as does the English 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 centimeters; 1.0 square meter = 10,000 square centimeters. In the English system, one square foot is equal to 144 square inches.

2-3.3 Volume. Volume or capacity is expressed as 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. In addition to cubic feet, the English System uses other units of volume or capacity such as gallons and bushels. No simple relationship exists between these units of volume and the cubic measurements, and consequently calculations involve the uses of numerous conversion factors. 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).

2-3.4 Weight. The kilogram (kg) is the standard metric unit of mass or weight. One kilogram is defined as the mass of one liter of water or about 2.2 pounds at 4°C. For smaller masses the gram (g) and milligram (mg) are used.

Example: Convert 180 pounds to kilograms.

Solution: Step 1. 1 kilogram = 2.2 pounds.

$$\frac{180\ pounds}{2.2\ pounds/kilogram} = 81.8\ kilograms$$

2-3.5 Pressure. Small pressures and partial pressures of gases are usually expressed as the height of a column of fresh water or mercury. Conversion factors for commonly used pressure units are found in Appendix C.

2-3.6 Temperature. Countries using the English System of weights and measures employ the Fahrenheit (°F) temperature scale. Countries that use the Metric System, and most scientific laboratories, use the Celsius (°C) (formerly centigrade) scale. This scale is based upon the temperature of melting ice (32°F) as 0°C and the temperature of boiling water (212°F) as 100°C.

Conversion from one temperature scale to another may be accomplished by using the following equations:

To convert from Fahrenheit to Celsius:

$$°C = 5/9 \times (°F - 32)$$

$$= 0.56 \times (°F - 32)$$

To convert from Celsius to Fahrenheit:

$$°F = (9/5 \times °C) + 32$$

$$= (1.8 \times °C) + 32$$

A temperature conversion chart is found in Appendix C.

Absolute temperature values are used when making certain types of calculations, such as when employing the ideal gas laws. The absolute temperature scales are based upon absolute zero (the lowest temperature that could possibly be reached) at which all molecular motion would cease. On the Fahrenheit scale this temperature is -460°F; in Celsius it is -273°C.

To convert from Fahrenheit to absolute temperature (degrees Rankine, °R):°R = °F + 460

To convert from Celsius to absolute temperature (Kelvin):

Kelvin (K) = °C + 273

A comparison of the four temperature scales is depicted in Figure 2-4.

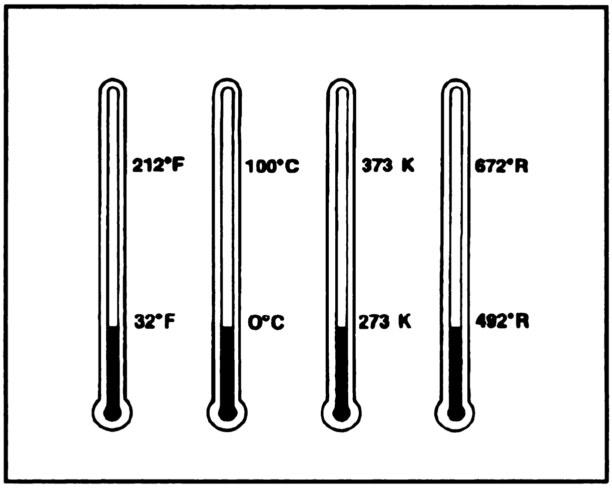


Figure 2-4. Temperature Scales. Fahrenheit, Celsius, Kelvin, and Rankine temperature scales showing the freezing and boiling points of water.

2-4 PRESSURE IN DIVING

Pressure can be defined simply as a force (or weight) acting upon a particular area of matter. It is typically measured in pounds per square inch (psi) in the English system and kilograms per square centimeter (kg/cm2) in the metric system.

Under the sea, pressure is a result of two factors: first, the weight of the water surrounding and above the diver; and, second, the weight of the atmosphere over that water.

Throughout this discussion of the forces affecting the diver, there is one concept that must be remembered at all times: any diver, at any depth, must be in pressure balance with the forces at that depth. The body can only function normally when the pressure difference between the inside of the diver's body and forces acting outside is very small.

Any consideration of pressure, whether of the atmosphere, of seawater, or of the gases being furnished for breathing, must always be thought of in terms of attaining and maintaining pressure balance.

2-4.1 Atmospheric Pressure. The early scientists who first discovered gases did so through a series of experiments that provided the basic understanding needed to develop scientific formulas still in use today. The ancient Greeks were satisfied that air had substance even though it could not be seen or touched. Air, as wind or exhaled breath, could be felt, and air had sufficient substance (even though unseen) to block the passage of water if trapped in a tube. This can easily be demonstrated as shown in Figure 2-5.

In the 17th century, Galileo Galilei, an Italian scientist, made a major step forward in the understanding of gases when he found that air actually has weight. He took a sealed container, filled with nothing but trapped air, and balanced it on a scale against a pile of sand. Then he pumped more air into the container, resealed it, and put it back on the scale. The air then weighed more than the sand and was exerting a greater force on the scale platform.

Soon after this, an Italian mathematician named Evangelista Toricelli heard of Galileo's experiment. Toricelli reasoned that because we live submerged at the bottom of an ocean of air, we must also live under some constant weight exerted by that air.

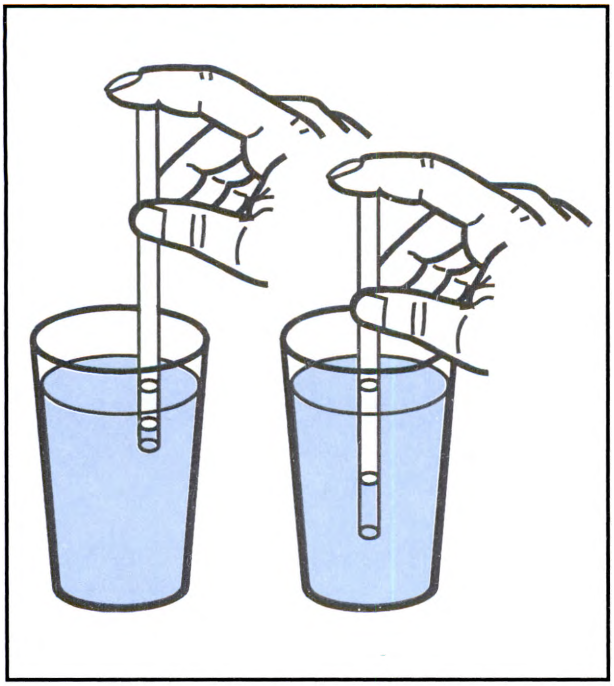


Figure 2-5. Air has Substance. Put a finger over one end of a soda straw and push the other end down into a glass of water. No matter how far down you push the straw, the water will not rise in the straw to match the water level in the glass.

Determined to measure the weight of the atmosphere, Toricelli started with a well-known but puzzling fact: using a suction pump, it was impossible to pump fresh water out of a well where the water had to rise more than 34 feet (10.4 meters). He theorized that the rise of water was caused by the weight of the air in the atmosphere, pushing the water into the vacuum created by the removed air.

To reduce the size of his apparatus, Toricelli substituted mercury (13.6 times heavier) for water. He took a four-foot glass tube, sealed at one end, and filled it completely with mercury. With a finger over the open end, he turned the tube upside down and submerged the covered end in a bowl also filled with mercury. When he removed his finger from the end of the tube, the mercury in the tube dropped until about 30 inches of mercury (760 mm Hg) remained in the tube. Above the mercury was a vacuum created by the falling liquid. Toricelli was thereby able to state that the weight of the air, pressing on the mercury in the bowl, was sufficient to offset the weight of a 30-inch column of mercury (760 mm Hg). This phenomenon is depicted in Figure 2-6.

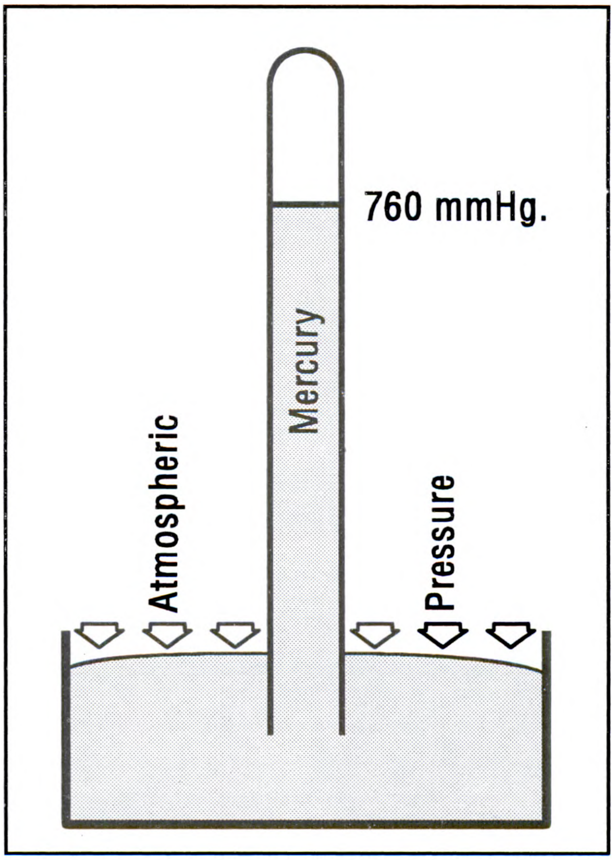


Figure 2-6. Toricelli's Barometer.

Blaise Pascal, the French philosopher/scientist, later repeated Toricelli's experiment in full scale using glass tubes. He demonstrated that the weight of a column of air reaching miles above the earth would balance and was therefore equal to the weight of a column of fresh water 34 feet high (or a column of sea water, which is heavier, 33 feet high). This would hold true if the air and water columns were one-inch square in cross section, or one-foot square or even one-mile square, as long as the same area measurement was applied to the columns.

This information can be used to compute a convenient measure of atmospheric pressure, expressed as pounds per square inch (psi). Assuming that a column is one-foot square in cross section, and knowing that the weight of a cubic foot of sea water is 64 pounds, it follows that the weight of a 33-foot column of sea water is 2,112 pounds. This is the pressure acting on one square foot at sea level. To reduce this to pounds per square inch, 2,112 is divided by 144 (144 square inches equals one square foot), giving a value of 14.7 psi. This is called atmospheric pressure, and 14.7 psi is the value of the unit of pressure measurement known as one atmosphere.

Given that one atmosphere is equal to 33 feet of sea water or 14.7 psi, 14.7 psi divided by 33 feet equals 0.445 psi. Thus, for every foot of sea water, the total pressure is increased by 0.445 psi.

Atmospheric pressure is considered to be constant at sea level, with minor fluctuations caused by the weather usually discounted. This pressure is also universal, acting on all things in all directions so that everything on the surface of the earth tends to be in a pressure balance. The pressure inside your body, for example, is the same as the pressure outside.

Because atmospheric pressure is universally applied, it does not register on the pressure gauge of a cylinder of compressed air. The air in the cylinder and the gauge are already under a base pressure of one atmosphere (14.7 psi or 1 kg/cm^2). The gauge measures the pressure difference between the atmosphere and the air in the tank. This reading is called gauge pressure, and for most purposes it is sufficient. However, in some applications (especially in diving) it is important to include atmospheric pressure in computations. This total pressure is called absolute pressure and is normally expressed in units of atmospheres. The distinction is important, and pressure must be identified as either gauge (psig) or absolute (psia). When the type of pressure is identified only as psi, it refers to gauge pressure. Conversion factors for the various units of pressure measurement are found in Appendix C.

To summarize, four terms are used to describe gas pressure:

(1) Atmospheric - Usually expressed as one kg/cm^2, 14.7 psi or one atmosphere absolute (one ata).

(2) Barometric - Essentially the same as atmospheric but varying with the weather and expressed in terms of the height of a column of mercury (standard pressure equaling 29.92 inches of mercury or 760 millimeters of mercury).

(3) Gauge - Indicates the difference between atmospheric pressure and the pressure being measured.

(4) Absolute - The total pressure being exerted (i.e., gauge pressure plus atmospheric pressure).

Figure 2-7 illustrates the various different units used to measure gage pressure.

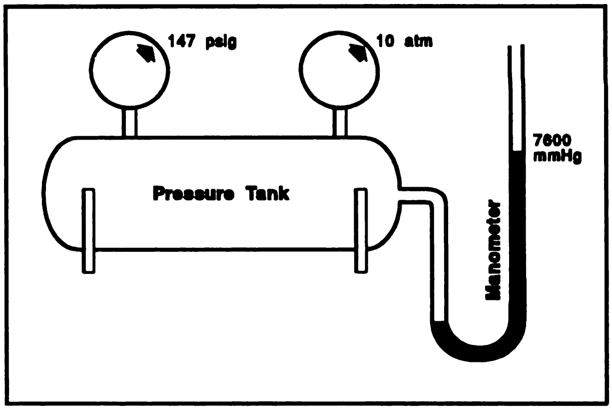


Figure 2-7. Units of Pressure. Pressure is commonly expressed in atmospheres (atm), pounds per square inch gauge (psig), and millimeters of mercury (mmHg).

2-4.2 Hydrostatic Pressure. Certain physical properties of water bring an extra dimension to the study of pressure as it affects a diver. With a gas, pressure is increased by pumping more molecules into a container, reducing the volume of the container, or heating the gas in a closed container.

In water, pressure is a direct result of the weight of the water, and this pressure from weight is cumulative. The water on the surface pushes down on the water below, and so on down to the bottom where, at the greatest depths of the ocean (approximately 36,000 feet), the pressure is more than eight tons per square inch (1,100 ata). This force, due to the weight of the water column, is referred to as hydrostatic pressure.

Recalling the findings of Toricelli and Pascal, we know that the pressure of seawater at a depth of 33 feet will be equal to one atmosphere. The absolute pressure, which is a combination of atmospheric and water pressure for that depth, will be two atmospheres. For every additional 33 feet of depth, another atmosphere of pressure (14.7 psi) will be encountered. Thus, at 99 feet, the absolute pressure will be equal to four atmospheres.

Table 2-1 illustrates increasing pressure.

Table 2-1. Pressure Chart.

Depth (Gauge Pressure)	Atmospheric Pressure	Absolute Pressure
0	One Atmosphere	1 ata (14.7 psia)
33 fsw	+ One Atmosphere	2 ata (29.4 psia)
66 fsw	+ One Atmosphere	3 ata (44.1 psia)
99 fsw	+ One Atmosphere	4 ata (58.8 psia)

This change in pressure with depth is so pronounced that the feet of a six-foot tall person standing underwater will be exposed to pressure that is almost three pounds per square inch greater than that exerted at his head.

2-4.3 Buoyancy. Buoyancy is the force that makes objects float, whether they are pieces of cork or ships with steel hulls. It was first defined by the Greek mathematician Archimedes, who established that *"Any object wholly or partly immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object"*. This is known as Archimedes' Principle, and it applies to all objects and all fluids. Figure 2-8 illustrates the principle of buoyancy.

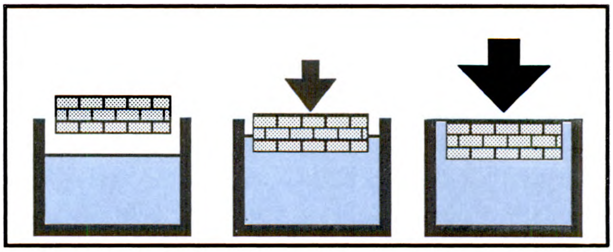


Figure 2-8. Buoyancy. As a block is immersed in a liquid, it displaces a volume of liquid. The weight of the volume of liquid displaced is equal to the buoyant force on the block.

Using Archimede's Principle to determine the buoyant force, the buoyancy of a submerged body can be established by subtracting the weight of the submerged body from the weight of the displaced liquid.

If the total displacement (the weight of the displaced liquid) is greater than the weight of the submerged body, the buoyancy will be positive, and the body will float or be buoyed upward. If the weight of the body is equal to that of the displaced liquid, the buoyancy will be neutral, and the body will remain suspended in the liquid. If the weight of the submerged body is greater than that of the displaced liquid, the buoyancy will be negative, and the body will sink. Figure 2-9 illustrates the various stages of buoyancy.

The buoyant force of a liquid is dependent upon its density, which is its weight per unit volume. Fresh water has a density of 62.4 pounds per cubic foot. Sea water is heavier, having a density of 64.0 pounds per cubic foot. Thus a body will be buoyed up by a greater force in seawater than in fresh water, making it easier to float in the ocean than in a fresh water lake.

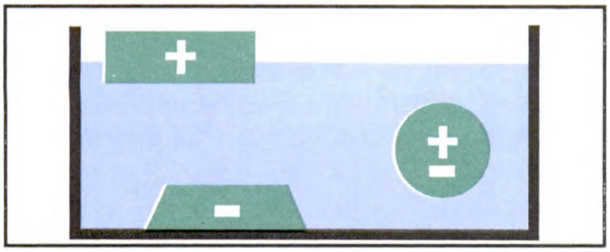


Figure 2-9. The Three Stages of Buoyancy. Positive buoyancy; indicating a tendency to float, negative buoyancy; which connotates a tendency to sink, and neutral buoyancy which reflects a condition of balance wherein an object will tend to neither rise nor sink but will remain suspended at any particular level.

Lung capacity can have a significant effect on buoyancy. With full lungs, a diver displaces a greater volume of water and, therefore, is more buoyant than with deflated lungs. Other individual differences that may affect buoyancy include bone structure, bone weight, and obesity or leanness. These differences explain why some individuals float easily while others do not.

A diver can vary his buoyancy in several ways. By adding weight to his gear, he can cause himself to sink. When wearing the MK 12 surface-supplied diving dress, he can increase or decrease the amount of air in his dress, thus changing his displacement and thereby his buoyancy.

Divers usually seek a condition of slightly negative buoyancy. For a diver in a helmet and dress, negative buoyancy gives him a better foothold on the bottom. For a diver using SCUBA, it enhances his ability to swim easily, change depth, and hover.

2-5 GASES IN DIVING

Knowledge of the properties and behavior of gases, especially those used for breathing, is vitally important to divers.

The most common gas used in diving is atmospheric air, the composition of which is shown in Table 2-2. Any gases found in concentrations different than those in Table 2-2 or that are not listed in Table 2-2 are considered contaminants. Depending on weather and location, many industrial pollutants may be found in air. Carbon monoxide is the most commonly encountered and is often present around air compressor engine exhaust. Care must be taken to exclude the pollutants from the divers' compressed air by appropriate filtering, inlet location and compressor maintenance. Water vapor in varying quantities is present in compressed air and its concentration is important in certain instances.

Table 2-2. Components of Dry Atmospheric Air.

	Concentration	
Component	**Percent by Volume**	**Parts per Million (ppm)**
Nitrogen	78.084	
Oxygen	20.946	
Carbon Dioxide	0.033	
Argon	0.0934	
Neon		18.18
Helium		5.24
Krypton		1.14
Xenon		0.08
Hydrogen		0.5
Methane		2.0
Nitrous Oxide		0.5

For most purposes and computations, diving air may be assumed to be composed of 79 percent nitrogen and 21 percent oxygen. Besides air, varying mixtures of oxygen, nitrogen, and helium are commonly used in diving.

While these gases are discussed separately, the gases themselves are almost always used in some mixture. Air is a naturally occurring mixture of most of them. In certain types of diving applications, special mixtures may be blended using one or more of the gases with oxygen.

- OXYGEN (O_2) - Oxygen is the most important of all gases, and is one of the most abundant elements on earth. Fire cannot burn without oxygen and people cannot survive without oxygen. Atmospheric air contains approximately 21 percent oxygen, which exists freely in a diatomic state (two atoms paired off to make one molecule). This colorless, odorless, tasteless and active gas readily combines with other elements. Water is about 89 percent oxygen by weight.

From the air we breathe, only oxygen is actually used by the body. The other 79 percent of the air serves to dilute and carry oxygen. Pure 100-percent oxygen is often used for breathing in hospitals, aircraft, and hyperbaric medical treatment facilities. Sometimes 100-percent oxygen is used in shallow diving operations and certain phases of mixed-gas diving operations. However, if a person breathes pure oxygen under pressure, he may experience the serious problems of oxygen toxicity (refer to Chapter 3).

- NITROGEN (N_2) - Like oxygen, nitrogen is diatomic, colorless, odorless, tasteless, and is a component of all living organisms. Unlike oxygen, it will not support life or aid combustion, and it does not combine easily with other elements. Nitrogen in the air is inert in the free state and is essentially a carrier for the oxygen. For diving, nitrogen may be used to dilute oxygen. Nitrogen is not the only gas that can be used for this purpose and under some conditions it has severe disadvantages as compared to other gases. Nitrogen narcosis (refer to Chapter 8), a disorder resulting from the anesthetic properties of nitrogen breathed under pressure, can result in a loss of orientation and judgment by the diver. For this reason, compressed air (with its high nitrogen content) is not used below a specified depth in diving operations.

- HELIUM (He) - Helium is also a colorless, odorless, and tasteless gas but it is monatomic (exists as a single atom in its free state). It is totally inert. Helium is a rare element, found in air only as a trace element of about 5 parts per million (ppm). It was first discovered in 1868 through spectrographic analysis of the sun, and was isolated on Earth in 1895. Helium is seven times lighter than air and is used primarily for inflating balloons and dirigibles. Helium coexists with natural gas in certain wells in the southwestern United States, Canada, and Russia. These wells provide the world's supply.

  When used in diving to dilute oxygen in the breathing mixture, helium does not cause the same problems associated with nitrogen narcosis, but it does have unique disadvantages. Among these is the distortion of speech which takes place in a helium atmosphere. The "Donald Duck" effect is caused by the unusual acoustic properties of helium, and it impairs voice communications in deep diving. Another negative characteristic of helium is its high thermal conductivity, which can cause rapid loss of body and respiratory heat.

- HYDROGEN (H_2) - Hydrogen is diatomic, colorless, odorless, and tasteless, and is so active that it is rarely found in a free state on earth. It is, however, the most abundant element in the rest of the universe. The sun and stars are almost pure hydrogen. Pure hydrogen is violently explosive when mixed with air in proportions that include a presence of more than 5.3 percent oxygen.

  Hydrogen has been used in diving (replacing nitrogen for the same reasons as helium) but the hazards have limited this to little more than experimentation. Because helium has been so readily available in the United States, the U.S. Navy has never had cause to use hydrogen for normal diving operations.

- NEON (Ne) - Neon is inert, monatomic, colorless, odorless, tasteless, and is found in minute quantities in the atmosphere. It is a heavy gas, and does not exhibit the narcotic properties of nitrogen when used as a breathing medium. Because it does not cause the speech distortion problem associated with helium, and has superior thermal insulating properties, it has been the subject of some experimental diving research.

- CARBON DIOXIDE (CO_2) - Carbon dioxide is colorless, odorless, and tasteless when found in small percentages in the air. In greater concentrations it has an acid taste and odor. Carbon dioxide is a natural by-product of the respiration of animals and humans and is formed by the oxidation of carbon in food to produce energy. For divers, the two major concerns with carbon dioxide are control of the quantity in the breathing supply, and removal of the exhaust after breathing.

  While some CO_2 is essential, unconsciousness can result when it is breathed at increased partial pressure. In high concentrations the gas can be extremely toxic or fatal. In the case of closed and semi-closed breathing apparatus, the removal of excess carbon dioxide generated by breathing is essential to safety.

- CARBON MONOXIDE (CO) - Carbon monoxide does not naturally occur in any quantity in the air. It is produced by incomplete combustion of fuels and is most commonly found in the exhaust of internal combustion engines. It is a poisonous gas that is colorless, odorless, tasteless, and difficult to detect. Carbon monoxide is highly active chemically and seriously interferes with the ability of the blood to carry oxygen (refer to Chapter 3).

  Great care shall be taken when SCUBA cylinders are being filled because a possible source of CO contamination may be the exhaust system of the air compressor itself. The usual carbon monoxide problem for divers is contamination of the air supply by placement of the compressor intake too close to the compressor exhaust. In such a situation, the exhaust gases are sucked in with the air and sent on to the diver, often with disastrous results.

2-5.1 Kinetic Theory of Gases. On the surface of the earth the constancy of the atmosphere's pressure and composition tend to be accepted without concern. To the diver, however, the nature of the high pressure, or hyperbaric, gaseous environment assumes great importance. The basic explanation of the behavior of gases under all variations of temperature and pressure is known as the kinetic theory of gases.

The term kinetic is derived from a Greek word meaning motion, which is the normal condition of a gas. The molecules are always in high-speed motion, continually rebounding off each other in all directions. In fact, the word gas was taken from the Greek word chaos because it seemed so apt a description of this kinetic activity.

The kinetic energy of a gas is related to the speed at which the molecules are moving and the mass (weight) of the gas. Speed is a function of temperature, and mass is a function of gas type. At a given temperature, molecules of heavier gases move at slower speed than those of lighter gases, but their combination of mass and speed results in the same kinetic energy level and impact force. The measured impact force, or pressure, is representative of the kinetic energy of the gas.

The kinetic theory of gases states: *"The kinetic energy of any gas at a given temperature is the same as the kinetic energy of any other gas at the same temperature".* Consequently, the measurable pressures of all gases resulting from kinetic activity are affected by the same factors.

For any given gas, if the number or force of the impacts is changed, the pressure will change. If the temperature is increased, for example, the increased speed of the molecules will cause impacts of higher force and greater frequency. If the temperature is reduced, the movement will be slower and the measured pressure, therefore, less. The pressure will also change if the volume of a gas is changed. By squeezing a given quantity of gas molecules into a smaller volume, the number of impacts per square inch of container wall will increase and so will the pressure. The same result occurs if more molecules of a gas are pumped into a given volume - more molecules, more impacts, higher pressure. This is illustrated in Figure 2-10.

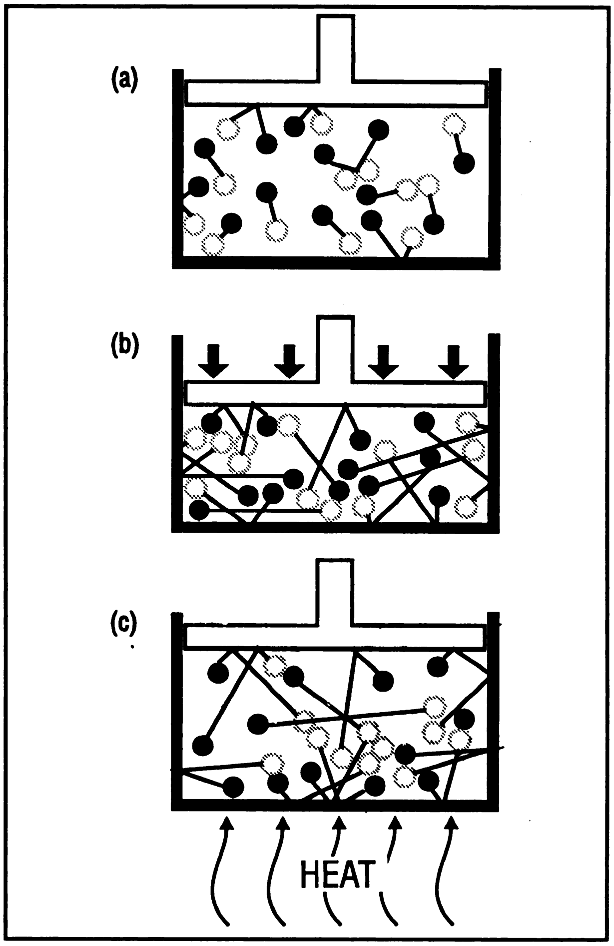


Figure 2-10. Kinetic Energy. The kinetic energy of the molecules inside the container (a) produces a constant pressure on the internal surfaces.As the container volume is decreased (b), the molecules per unit volume (density) increase and so does the pressure. As the energy level of the molecules increases from the addition of thermal energy (heat), so does the pressure (c).

2-5.2 Gas Laws. Gases are subject to three closely interrelated factors: temperature, pressure, and volume. As the kinetic theory of gases points out, a change in one of these factors must result in some measurable change in the other factors. Further, the theory indicates that the kinetic behavior of any one gas will be the same for all gases or mixtures of gases. Consequently, basic laws have been established to help predict the changes that will be reflected in temperature, pressure, or volume as the conditions of the operating environment change.

A diver needs to know what effect changing pressure will have upon the air in his suit and in his lungs as he moves up and down in the water. He must be able to determine the capability of an air compressor to deliver an adequate supply of air to a proposed operating depth. He also needs to be able to interpret the reading on the pressure gauge of his tanks under varying conditions of temperature and pressure. The answers to such questions are calculated using a set of rules called the gas laws. The gas laws of direct concern to divers are:

- Boyle's Law
- Charles' Law
- Gay-Lussac's Law
- The General Gas Law

- Dalton's Law

- Henry's Law

2-5.2.1 Boyle's Law. In 1660, having heard of the discoveries of Toricelli and Pascal, Robert Boyle set out to determine what would happen to a given quantity of confined air if the pressure were changed. Boyle took a J-shaped tube of glass and sealed the short leg. He then poured mercury into the longer leg until the amount of mercury in each leg was equal. At that point, he reasoned that the pressure of the air trapped in the closed end of the tube must be equal to the pressure of the atmosphere acting on the mercury in the longer, open end. Boyle then added more mercury until he could see that the volume of air trapped in the short leg was cut in half. This took an added 30 inches (760 millimeters) of mercury, which meant that he had added an amount equal to atmospheric pressure and had thus doubled the pressure of the trapped gas.

Boyle's demonstration showed that for any gas at a constant temperature, the volume of a gas will vary inversely with the absolute pressure while the density will vary directly with the absolute pressure. That is, the higher the pressure the smaller the volume, and vice-versa.

Boyle's law states: *"For any gas at a constant temperature, the volume of the gas will vary inversely with the pressure"*.

$$P \times V = K \text{ or } P_1V_1 = P_2V_2$$

Where:

P = *absolute pressure*

V = *volume*

K = *a constant*

Boyle's Law is important to divers because it relates change in the volume of a gas caused by the change in pressure, due to depth and volume, and defines the relationship of pressure and volume in breathing gas supplies. The following example illustrates Boyle's Law.

Example: An open diving bell with a volume of 24 cubic feet is to be lowered into the sea from a support craft. No air is supplied to or lost from the bell. Calculate the volume of the air space in the bell at the 33-foot, 66-foot, and 99-foot depths.

Step 1 - Boyle's Law (at surface)

$P_1V_1 = K$

P_1 = *pressure at surface in ata*

V_1 = *volume at surface in cubic feet*

K = *constant*

Step 2 - Boyle's Law (at 33 feet)

$P_2V_2 = K$

P_2 = *pressure at 33 feet in ata*

V_2 = *volume at 33 feet in cubic feet*

K = *constant*

Step 3 - Equating the constant K at the surface and at 33 feet, we have the following equation:

$P_1V_1 = P_2V_2$

Transposing to determine the volume at 33 feet, V2:

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

P_1 = *1 atmosphere (ata)*

P_2 = *2 ata*

$V_1 = 24\,ft^3$

$$V_2 = \frac{1\,ata \times 24\,ft^3}{2\,ata}$$

$V_2 = 12\,ft^3$

Note that the volume of air in the open bell has been compressed from 24 to 12 cubic feet in the first 33 feet of seawater.

Step 4 - Using the method illustrated above, determine the air volume at 66 feet:

$$V_3 = \frac{P_1 V_1}{P_3}$$

$P_3 = 3\,ata$

$$V_3 = \frac{1\,ata \times 24\,ft^3}{3\,ata}$$

$V_3 = 8\,ft^3$

Step 5 - For the 99-foot depth, using the method illustrated previously, the air volume would be:

$$V_4 = \frac{P_1 V_1}{P_4}$$

$P_4 = 4\,ata$

$$V_4 = \frac{1\,ata \times 24\,ft^3}{4\,ata}$$

$V_4 = 6\,ft^3$

As depth increased from the surface to 99 feet, the volume of air in the open bell was compressed from 24 cubic feet to 6 cubic feet.

If the bell is returned to the surface, the volume will return to the original amount as the pressure is reduced to one atmosphere.

A balloon of air can be likened to the air in a diver's lungs. As the diver descends, the air will be compressed; as he ascends, it will expand. The changes will always be in proportion to the changes in the absolute pressure and, because of this, the changes will be most pronounced in the water nearest the surface.

In the previous illustration, the amount of air was reduced in volume to one-half in the change from one atmosphere at the surface to two atmospheres at 33 feet, and to one-quarter at 99 feet.

The change between 33 feet and 66 feet was much less than that between the surface and 33 feet; a change of only 4 cubic feet compared to 12 cubic feet. An understanding of this relationship is important to a diver because it indicates that sudden changes of depth while in shallow water can be more dangerous than equivalent changes of depth while working in deeper water. Actually, the change in gas volume in the last 33 feet of an ascent would be greater than the change that would occur in ascending from a depth of 297 feet to 33 feet. At 297 feet (10 ata), the volume of the air space would be 2.4 cubic feet. A rise through the water column to 33 feet and the subsequent decrease in external pressure means the air space would reach a volume of 12 cubic feet, or an increase of only 9.6 cubic feet. From 33 feet to the surface, the increase would be 12 cubic feet, actually doubling the volume.

The following is an illustration of Boyle's Law applied to a specific diving situation, one in which a lack of knowledge of the law could have lethal consequences.

Example: As part of a training exercise, you have been scheduled to make a free ascent from a depth of 66 fsw (20 meters). On the bottom, an instructor takes your SCUBA gear and lets you have one final breath before the ascent. Naturally enough, you take in as much air as you can, filling your lungs. Then you push up toward the surface.

While you were at 66 fsw breathing normally from your SCUBA, you were in pressure balance with your immediate environment. The absolute pressure at that depth is three atmospheres. The regulator on your SCUBA was automatically delivering breathing air at the same pressure, so that the air inside your lungs balanced the outside pressure. Your lungs were at their normal size and capacity, and that last breath just filled them to about five liters.

You start to rise, and the pressure starts to decrease. As predicted by Boyle's Law, the volume of gas (the air in your lungs) will increase proportionally. By the time you reach 33 feet, if you have not allowed any air to escape, the air in your lungs will have increased in volume by one-half to match the one-third reduction in absolute pressure. Your lungs will now be straining and the air will be trying to bubble its way past your lips. But, being an inexperienced diver, your natural tendency is to try to hold in the air so that you will have enough to last until you reach the surface which still appears to be a long way up.

If you hold your breath in an attempt to contain the air, by the time you reach the surface that lungful of air will have expanded to three times the normal lung capacity. In all probability, the overinflation of your lungs will have caused an arterial gas embolism (refer to Chapter 3), a serious medical disorder caused by gas bubbles being forced through the lung tissue into the blood stream. For this reason, free-ascent training emphasizes the need for continuous blowing out of the expanding air and warns of the dangers of breathholding.

In Boyle's Law, the temperature of the gas was considered to be a constant value. However, temperature significantly affects the pressure and volume of a gas. It is essential for divers to know the effect of temperature because the temperature deep in oceans and lakes is often significantly different from the air temperature at the surface. The gas law that describes the physical relationships of temperature upon the volume is known as Charles' Law.

2-5.2.2 Charles' Law. Boyle had shown that at a constant temperature, pressure and volume were inversely related. However, because his experiments were conducted at relatively low pressures and at whatever the temperature happened to be on the day of his experiments, they provided no clues as to the influence of temperature. A French scientist, Jacques Charles, found that temperature does indeed influence gas volume.

Charles' Law states: *"For any gas at a constant pressure, the volume of the gas will vary directly with the absolute temperature".*

Charles' Law can be expressed as:

$$\frac{V}{T} = K$$

$$\text{or } \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Where: Pressure is constant

T_1 = *initial temperature (absolute)*

T_2 = *final temperature (absolute)*

V_1 = *initial volume*

V_2 = *final volume*

K = *constant*

The following example illustrates Charles' Law:

An open diving bell of 24 cubic feet capacity is lowered into the ocean to a depth of 99 feet. At the surface the temperature is 80°F, and at depth the temperature is 45°F. What is the volume of the gas at 99 feet?

Solution: From the example illustrating Boyle's Law, we know that the volume of the gas was compressed to six cubic feet when the bell was lowered to the 99-foot level. The application of Charles' Law illustrates the further reduction of volume due to temperature effects.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \text{ Where: } V_1 = \text{volume at depth, } 6\,ft^3$$

$T_1 = 80°F + 460 = 540°R$

$T_2 = 45°F + 460 = 505°R$

$$\textit{Transposing and substituting: } V_2 = \frac{V_1 T_2}{T_1}$$

$$V_2 = \frac{6 \times 505}{540}$$

$$V_2 = 5.61\,ft^3$$

2-5.2.3 Gay-Lussac's Law. Joseph Gay-Lussac (1778 - 1850), a French scientist, discovered another gas law, the pressure-temperature law, which explained what would happen if a steel cylinder of a certain volume were pressurized to a specific pressure and then heated.

Gay-Lussac's Law states: *"For any gas at a constant volume, the pressure of the gas will vary directly as the absolute temperature"*. This law can be expressed as:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Where: Volume is constant

P_1 = *initial pressure (absolute)*

P_2 = *final pressure (absolute)*

T_1 = *initial temperature (absolute)*

T_2 = *final temperature (absolute)*

The following example illustrates Gay-Lussac's Law:

A six cubic-foot flask is charged to 3000 psig and the temperature in the flask room is 72°F. A fire in an adjoining space causes the temperature in the flask room to reach 170°F. What will happen to the pressure in the flask?

Solution: Applying Gay-Lussac's Law,

$P_1 = 3014.7\,psia$

$P_2 = ?$

$T_1 = 72°F + 460 = 532°R$

$T_2 = 170°F + 460 = 630°R$

Transposing and substituting:

$$P_2 = \frac{P_1\,T_2}{T_1}$$

$$P_2 = \frac{3014.7 \times 630}{532} = 3570.03\,psia$$

Note that even though neither the volume of the container nor the volume of gas within the container changed, the pressure increased. This illustration shows what would happen to a SCUBA cylinder that was filled to capacity and left unattended in the trunk of an automobile or lying in direct sunlight on a hot day.

2-5.2.4 The General Gas Law. Boyle, Charles, and Gay-Lussac demonstrated that for gases, the factors of temperature, volume, and pressure are so interrelated that a change in any of these factors must be balanced by corresponding change in one or both of the others. Boyle's Law illustrates pressure/volume relationships, Charles' Law describes the relationship between temperature and volume and Gay-Lusac's Law describes the relationship between temperature and pressure. The General Gas Law is a convenient combination of these three laws used to predict the behavior of a given quantity of gas when changes may be expected in any or all of the variables. This is expressed mathematically as follows:

$$\frac{P_1 V_1}{T_1} = K \text{ or } \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Where: P_1 = *initial pressure (absolute)*

V_1 = *initial volume*

T_1 = *initial temperature (absolute)*

P_2 = *final pressure (absolute)*

V_2 = *final volume*

T_2 = *final temperature (absolute)*

K = *constant*

In working with this formula, a few simple rules must be kept in mind:

(1) There can be only one unknown.

(2) If it is known that a value remains unchanged (such as the volume of an air cylinder) or that the change in one of the variables will be of little consequence, cancel the value out of both sides of the equation, thus simplifying the computations.

The following are examples of uses of the General Gas Law in a typical diving operation.

Your ship has been assigned to locate and salvage an LCM landing craft which has been damaged and sunk in a recent exercise. The LCM is located in 130 feet of water and an exploratory dive to survey the wreckage is planned. The dive will be of short duration and SCUBA will be used.

As the air cylinders of the SCUBA are being charged to a capacity of 2,250 psig, the temperature in the tanks rises to 140°F. From experience in these waters, you know that the temperature at the operating depth will be about 40°F, and you want to know what the gauge reading will be when you first reach the bottom.

For the first step in computing the answer, fill in all known values:

P_1 = *2,250 psig + 14.7 (atmospheric) = 2,264.7 psia*

$V_1 = V_2$ *(the volume of the tank will not change, so V can be eliminated in this problem)*

Convert the temperature from degrees Fahrenheit to its absolute equivalent in degrees Rankine:

$°R = °F + 460$

$T_1 = 140°F + 460 = 600°R$

$T_2 = 40°F + 460 = 500°R$

P_2 = *Unknown*

With V eliminated from the formula, it now reads:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

P_2 is solved for by rearranging the formula:

$$P_2 = \frac{P_1 T_2}{T_1}$$

Substituting:

$$P_2 = \frac{2{,}264.7\ psia \times 500°R}{600°R} = 1{,}887.25\ psia$$

Adjust P_2 to gauge pressure:

1,887.25 psia - 14.7 = 1,872.55 psig

During the survey dive, the divers determined that the damage will require a simple patch. For this job, the Diving Supervisor elects to use surface-supplied MK 12 equipment.

The Diving Supervisor makes a calculation to ascertain that the compressor capacity is adequate to deliver the proper volume of air to both the working diver and the standby diver at the operating depth and temperature.

The compressor has a suction capacity of 60 cubic feet per minute, and the temperature of the air on the deck of the ship is 80°F. The pressure at working depth is approximately five atmospheres absolute (ata). This is derived by dividing the depth (130 feet) by the increment of depth which has a pressure equal to one atmosphere (33 feet) and adding one atmosphere to give absolute pressure. The problem can be solved using either psi values or units of atmospheres, but not both in the same problem. Using atmospheres simplifies the arithmetic. The absolute temperatures are 540°R on the surface (80°F + 460) and 500°R at depth, as computed in the first example.

Rearrange the formula to solve for the unknown, the volume of air at depth:

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}$$

Substitute values and solve:

$$V_2 = \frac{1\ ata \times 60cfm \times 500°R}{5\ ata \times 540°R}$$

$$= 11.1\ acfm\ at\ bottom\ conditions$$

Based upon an actual volume (displacement) flow requirement of 4.5 acfm for a deep-sea diver (Chapter 6), the compressor capacity is sufficient to support the working and standby divers (9.0 acfm) at 130 fsw.

2-5.3 Gas Mixtures. If a diver used only one gas for all underwater work, at all depths, then the General Gas Law would suffice for most of his necessary calculations. However, to accommodate use of a single gas, oxygen would have to be chosen since it is the only one which provides life support. But, 100-percent oxygen can be dangerous to a diver as depth and breathing time increase.

Divers usually breathe gases in a mixture, either air (21-percent oxygen, 78-percent nitrogen, 1-percent other gases), or oxygen with one of the inert gases serving as a carrier for the oxygen. The human body has a wide range of reactions to various gases under different conditions of pressure, and for this reason another gas law is required to help compute the differences between breathing at the surface and breathing under pressure.

2-5.3.1 Dalton's Law. Dalton's Law states: *"The total pressure exerted by a mixture of gases is equal to the sum of the pressures of each of the different gases making up the mixture, with each gas acting as if it alone was present and occupied the total volume"*.

In a gas mixture, the portion of the total pressure contributed by a single gas is called the partial pressure (pp) of that gas. An easily understood example is that of a container at atmospheric pressure (14.7 psi). If the container were filled with oxygen alone, the partial pressure of the oxygen would be one atmosphere. If the same container at 14.7 psi (1 atm) were filled with dry air, the partial pressures of all the constituent gases would contribute to the total partial pressure, as shown in Table 2-3.

Table 2-3. Partial Pressure at 1 ATA.

Gas	Percent of Component	Atmospheres Partial Pressure
N_2	78.08	0.7808
O_2	20.95	.2095
CO_2	.03	.0003
Other	.94	.0094
Total	100.00	1.0000

If the same container was filled with air to 2,000 psi (137 ata), the partial pressures of the various components would reflect the increased pressure in the same proportion as their percentage of the gas, as illustrated in Table 2-4.

Table 2-4. Partial Pressure at 137 ATA.

Gas	Percent of Component	Atmospheres Partial Pressure
N_2	78.08	106.97
O_2	20.95	28.70
CO_2	.03	.04
Other	.94	1.29
Total	100.00	137.00

Observe that while the partial pressures of some constituents of the gas, particularly CO_2, were fairly small at atmospheric pressure, they increased significantly at higher pressures. The implications of Dalton's Law are highly significant and should be understood by divers.

Dalton's Law can be described algebraically as:

$$P_{Total} = pp_A + pp_B + pp_C, \text{ etc.}$$

Where: A, B, and C are gases and

$$pp_A = \frac{P_{Total} \times \%\ Vol_A}{100\%}$$

Another, sometimes more convenient method of arriving at the same conclusion is to use the T formula, which is illustrated as:

$$\frac{pp}{ata \quad \big| \quad \%\ (in\ decimal\ form)\ O_2}$$

Example: Use the T formula to calculate oxygen partial pressure given 10 ata and 16% oxygen.

Solution: $\dfrac{1.6\ ppO_2}{10\ ata \ \big|\ .16}$

When working this formula, it is necessary that two "knowns" be furnished. After that, it is merely a case of multiplying across, or dividing up.

What happens to the breathing mixture at the operating depth of 130 feet (5 ata)? The air compressor on the ship is taking in air at the surface, normal pressure and normal mixture, and sending it to the diver at pressure sufficient to provide the necessary balance. The composition of air is not changed, but the quantity being delivered to the diver is five times what he was breathing on the surface. More molecules of oxygen, nitrogen, and carbon dioxide are all compressed into the same volume at the higher pressure. Use Dalton's Law to determine the partial pressures at depth:

Oxygen partial pressure (surface):

$$ppO_2 = 21\% \times 1\ ata = .21\ ata$$

Inert gas partial pressure (surface):

$$pp^I = 79\% \times 1\ ata = .79\ ata$$

Carbon dioxide partial pressure (surface):

$$ppCO_2 = 0.03\% \times 1\ ata \times 760\ mmHg = .228\ mmHg$$

Recalculate at 5 ata:

$$ppCO_2 = 0.03\% \times 5\ ata = .0015\% \times 760\ mmHg = 1.14\ mmHg$$

Expressing partial pressures of gases in atmospheres absolute (ata) is the most common method employed in large quantities of pressure. Partial pressures of less than 0.1 atmosphere are usually expressed in millimeters of mercury (mmHg). At the surface, atmospheric pressure is equal to 1 ata or 14.7 psia or 760 mmHg. Using the same formulas as before and substituting mmHg values in place of atmospheres, the same problems yield:

Oxygen partial pressure (ppO_2):

$$ppO_2 = \frac{21\%}{100\%} \times 760\ mmHg = 159.6\ mmHg$$

Inert gas (I) partial pressure (pp^I):

$$pp^I = \frac{79\%}{100\%} \times 760\ mmHg = 600.4\ mmHg$$

Carbon dioxide partial pressure ($ppCO_2$):

$$ppCO_2 = \frac{0.03\%}{100\%} \times 760\ mmHg = 0.228\ mmHg$$

Recalculate at 5 ata:

$$760\ mmHg \times 5\ ata = 3{,}800\ mmHg$$

Oxygen partial pressure:

$$ppO_2 = \frac{21\%}{100\%} \times 3{,}800\ mmHg = 798\ mmHg$$

Inert gas partial pressure:

$$pp^I = \frac{79\%}{100\%} \times 3{,}800\ mmHg = 3{,}002\ mmHg$$

Carbon dioxide partial pressure:

$$ppCO_2 = \frac{0.03\%}{100\%} \times 3{,}800\ mmHg = 1.14\ mmHg$$

From the previous calculations, it is apparent that the diver is breathing more molecules of oxygen at 130 fsw than he would be if using 100-percent oxygen (760 mmHg) at the surface. He is also inspiring five times as many carbon dioxide molecules as he would breathing normal air on the surface. If the surface air were contaminated with two percent (0.02 ata) carbon dioxide, a level which could be readily accommodated by a normal person at one ata, the partial pressure at depth would be dangerously high: 0.1 ata (0.02 x 5 ata). This partial pressure is commonly referred to as a surface equivalent value (sev) of ten percent carbon dioxide:

$$sev = \frac{pp\ at\ depth\ (in\ ata) \times 100\%}{1\ ata}$$

$$= \frac{0.1\ ata}{1\ ata} \times 100\% = 10\%\ CO_2$$

2-5.3.1.1. Gas Diffusion. Another physical effect of partial pressures and kinetic activity is that of gas diffusion. Gas diffusion is the process of intermingling or mixing of gas molecules. If two gases are placed together in a container, they will eventually mix completely even though one gas may be heavier. The mixing occurs as a result of constant molecular motion.

The amount of an individual gas which will move through a permeable membrane (a solid which permits molecular transmission) depends upon the partial pressure of the gas on both sides of the membrane. If the partial pressure is higher on one side than the other, the gas molecules will diffuse through the membrane to the lower partial pressure side until the partial pressure is equalized (equilibrium). Molecules are actually passing through the membrane at all times in both directions due to kinetic activity, but more will move from the side of higher concentration.

Numerous body tissues act as permeable membranes. Consequently, the rate of gas diffusion, which is related to the difference in partial pressures, is an important consideration in determining the uptake and elimination of gases in calculating decompression tables.

2-5.3.1.2. Humidity. Water vapor, like other gases, behaves in accordance with the gas laws. However, unlike other gases encountered in diving, water vapor condenses to its liquid state at temperatures normally encountered by man.

The amount of water vapor in gaseous atmospheres is referred to as humidity. In proper concentrations, water vapor in diving atmospheres aids the comfort of the diver by moistening body tissues. As a condensing liquid, however, water vapor can cause freezing and blockage of air passageways in hoses and equipment, fog a diver's faceplate, and corrode his equipment. Consequently, a knowledge of the behavior of water vapor under changing conditions of pressure, temperature, and volume is essential.

Humidity is related to the vapor pressure of water. If a quantity of water is placed in a jar and the jar is sealed, part of the water will evaporate into the space above the liquid. Water will continue to evaporate until the number of molecules of water vapor leaving the liquid surface is the same as the number returning. When this equilibrium condition is reached, the air space above the water is said to be saturated with water vapor.

The partial pressure of water in the gas is directly related to the temperature of the liquid water. As the water and gas temperature is increased, more molecules of water will evaporate into the gas until a new equilibrium condition and higher partial pressure are established.

If the liquid and gas are cooled, water vapor in the gas will condense until a lower partial pressure condition exists. This phenomenon will occur regardless of the total pressure of the gas above the liquid. Consequently, the maximum partial pressure of water vapor that can exist in a gas is governed entirely by the temperature of the gas.

2-5.3.2. Gases In Liquids. Whenever a gas is in contact with a liquid, a portion of the gas molecules will enter into solution with the liquid. They are said to be dissolved in the liquid. This factor of solubility is vitally important because significant amounts of gases are dissolved in body tissues at the pressures encountered in diving.

2-5.3.3. Solubility. Some gases are more soluble (capable of being dissolved) than others, and some liquids and substances are better solvents (capable of dissolving another substance) than others. For example, nitrogen is five times more soluble in fat than it is in water.

Apart from the individual characteristics of the various gases and liquids, there are two physical conditions that greatly affect the quantity of gas which will be absorbed: temperature and pressure. Because a diver is always operating under unusual conditions of pressure, an understanding of this factor is particularly important.

2-5.3.4. Henry's Law. Henry's Law states: *"The amount of any given gas that will dissolve in a liquid at a given temperature is a function of the partial pressure of that gas in contact with the liquid and the solubility coefficient of the gas in the particular liquid"*.

Because a large percentage of the human body is water, the law simply states that as one dives deeper and deeper, more gas will dissolve in the body tissues and that upon ascent, the dissolved gas must be released.

When a gas-free liquid is first exposed to a gas, quantities of gas molecules will rush to enter the solution, pushed along by the partial pressure of that gas. As the molecules enter the liquid, they add to a state of gas tension, which is a way of identifying the partial pressure of that gas in the liquid.

The difference between the gas tension and the partial pressure of the gas outside the liquid is called the pressure gradient, which gives an indication of the rate at which the gas will tend to enter or leave the solution.

At sea level, the body tissues are equilibrated with dissolved nitrogen at a partial pressure equal to the partial pressure of nitrogen in the lungs. Upon exposure to altitude or increased pressure in diving, the partial pressure of nitrogen in the lungs will change and tissues will either lose or gain nitrogen to reach a new equilibrium with the nitrogen pressure in the lungs. Taking up nitrogen in tissues is called absorption or uptake. Giving up nitrogen from tissues is termed elimination. In air diving, nitrogen absorption occurs when a diver is exposed to an increased nitrogen partial pressure.

Elimination occurs when pressure decreases. This is true for any inert gas breathed.

Absorption consists of several phases, including transfer of inert gas from the lungs to the blood and then from the blood to the various tissues through which it flows. The gradient for gas transfer is the partial pressure difference of the gas between the lungs and blood and between the blood and the tissues.

The volume of blood flowing through tissues is usually small compared to the mass of the tissue, but over a period of time the gas delivered to the tissue will cause it to become equilibrated with that carried in solution in the blood. As the number of molecules of gas in the liquid increases, the tension increases until it reaches a value equal to the partial pressure and at that point, the liquid is saturated with the gas and the pressure gradient is zero. Unless there is some change in temperature or pressure, the only molecules of gas to enter or leave the liquid are those which may, in random fashion, change places without altering the balance.

The rate of equilibration with the blood gas depends upon the volume of blood flow and the respective capacities of blood and tissues to absorb dissolved gas. For example, fatty tissues hold significantly more gas than watery tissues and will thus take longer to absorb or eliminate excess inert gas.

The solubility of gases is affected by temperature: the lower the temperature, the higher the solubility. If the temperature of an existing solution is increased, some of the gas already dissolved will leave solution. The bubbles which rise in a pan of water being heated (long before it boils) are bubbles of dissolved gas coming out of solution.

The gases in a diver's breathing mixture will be dissolved into his body in proportion to the partial pressure of each gas in the mixture. Because of the varied solubility of different gases, the quantity of a particular gas which becomes dissolved will also be governed by the length of time the diver is breathing the gas at the increased pressure. If the diver breathes the gas long enough, his body will become saturated. Saturation of the body occurs slowly. Depending on the gas, body tissue and pressure differential, it takes anywhere from 30 minutes to 72 hours.

Whatever the quantity of gas which has been dissolved in a diver's body, at whatever depth and pressure, it will remain in solution as long as the pressure is maintained. However, as the diver starts to ascend toward the surface, more and more of the dissolved gas will come out of solution. If his rate of ascent is controlled (i.e., through the use of the decompression tables) the dissolved gas will be carried to the lungs and exhaled before it accumulates sufficiently to form bubbles in the tissues. If, on the other hand, he ascends suddenly and the pressure is reduced at a rate higher than the body can accommodate, bubbles may form, disrupt body tissues and systems, and produce a condition known as decompression sickness.

The problems of decompression sickness are treated by recompression to dissolve the bubbles, and high partial pressures of oxygen to help the injured tissues, followed by slow decompression using special treatment tables which are discussed in detail in Chapter 8.

2-6 ENERGY IN DIVING

Four of the six types of energy, mechanical, heat, electrical, and chemical are commonly encountered in diving in a wide variety of forms. Only those forms which have unusual effects underwater (light, sound, and heat) are discussed here.

To function effectively in their environment, divers must understand the factors affecting underwater visual perception. One of these factors is light, which behaves differently in a dense medium such as water. As light passes from a medium of one density to another, light rays are bent and an effect known as refraction occurs. Refraction takes place at the surface, at the water and air interface, and at the interface between the water and the diver's mask.

Divers viewing objects through a faceplate experience refraction of light between the water and the air in their masks; this causes changes in the optical image and affects what is seen.

One such effect is that an object appears to lie at a distance approximately 3/4 of its actual distance. This distortion interferes with hand-eye coordination and accounts for the difficulty often experienced by novice divers attempting to grasp objects underwater (see Figure 2-11).

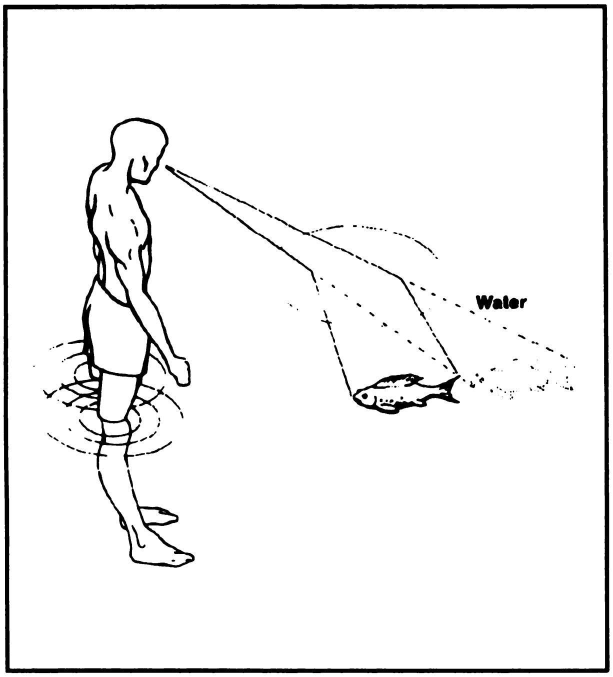


Figure 2-11. Objects Underwater Appear Closer.

At greater distances, however, this phenomenon may reverse itself, making distant objects appear farther away than they actually are. The reasons for overestimation of the distance of objects include reduced brightness and contrast combined with the absence of normal visual distance relationships.

All of these effects are influenced profoundly by the turbidity of the water - the more turbid the water, the shorter the distance at which the reversal from underestimation to overestimation occurs. For example, in highly turbid water, the distance of objects at three or four feet may be overestimated; in moderately turbid water, the change might occur at 20 to 25 fsw, and in very clear water, objects as far away as 50 to 70 fsw might appear closer than they actually are.

It is important for divers to realize that distance perception is very likely to be inaccurate and that errors of both underestimation and overestimation may occur. As a rough rule of thumb, the closer the object, the more it will appear to be too close, and the more turbid the water, the greater tendency to see it as too far away.

Changes in the optical image due to refraction also affect perception of size and shape. In general, objects underwater appear to be larger than they actually are by about 30 percent. This often is a cause of disappointment to sport divers, who find, upon bringing catches to the surface, that they are smaller than they appeared underwater.

Since refraction effects are greater for objects off to the side in the field of view, distortion in the perceived shape of objects is frequent. Misinterpretation of size, distance, and shape due to refraction can be overcome or compensated for with experience and training. How completely and how quickly one can learn to do this, however, depends upon many conditions.

Although the refraction that occurs between the water and the air in the diver's face mask produces these undesirable perceptual inaccuracies, air itself is essential for vision. For example, when the face mask is lost, the diver's eyes are immersed in water, which has about the same refractive index as the eye. Consequently, no normal focusing of light occurs in this situation, and the diver's vision is impaired immensely, to a level that would be classified as legally blind on the surface.

Though scattering occurs in air, it is intensified underwater. Light rays are diffused and scattered by the water molecules and particulate matter. At times diffusion is helpful because it scatters light into areas that otherwise would be in shadow or have no illumination. Normally, however, diffusion interferes with vision and underwater photography because the backscatter reduces the contrast between an object and its background. This loss of contrast is the major reason why vision underwater is so much more restricted than it is in air. Similar degrees of scattering occur in air only in unusual conditions such as heavy fog or smoke.

2-6.1 Visibility of Colors. Characteristics other than size and distance are distorted underwater; a variety of factors may combine to alter the accurate perception of color. The use of colored paints on objects is an obvious means of changing their visibility either by enhancing their contrast with the surroundings or by camouflaging them to merge with the background. Determining which colors will be most and least visible underwater is much more complicated than in air.

Changes in color occur because of scattering by the water itself, and scattering and absorption by particles in the water. Changes vary from one body of water to another and become more pronounced as the amount of water between the observer and the object increases. Certain conditions may cause the color red to be perceived as black. This is readily understandable when one considers that red objects appear red on the surface because of reflected red light. At depth no red light may reach the object to be reflected; hence, the object appears unlighted or black.

As light enters clear water and travels to depth, red light is filtered out at relatively shallow depths. Orange is filtered out next, followed by yellow, green, and then blue. The filtering of various colors is not dependent solely on depth. Other factors such as salinity, turbidity, size of the particles suspended in the water, or the degree and kind of pollution have effects on the color-filtering properties of water.

In general, the components of any underwater scene (e.g., weeds, rocks, encrusting animals) all tend to appear to be the same color as the depth or viewing range increases; they become distinguishable only by differences in brightness and not color. Contrast, whether light on dark or dark on light, becomes the most important factor in visibility, and even very large objects may be undetectable if their brightness is similar to that of the background.

2-6.2 Sound. Sound is a periodic motion or pressure change transmitted through a gas (air), a liquid (water), or a solid (rock). Because liquid is a denser medium than gas, more energy is required to disturb its equilibrium. Once this disturbance takes place, sound travels farther and faster in the denser medium. Several aspects of sound underwater are of interest to the working diver.

During diving operations, there may be two or more distinct contiguous layers of water at different temperatures; these layers are known as thermoclines. The colder a layer of water, the greater its density; as the difference in density between layers increases, less sound energy is transmitted between them. This means that a sound heard 50 meters (164 feet) from its source within one layer may be inaudible a few meters from its source if the diver is in another layer.

In shallow water or in enclosed spaces, reflections and reverberations from the air/water and object/water interfaces will produce anomalies (irregularities or abnormalities) in the sound field, i.e., echoes, dead spots, and sound nodes.

When a diver is swimming in shallow water, among coral heads, or in enclosed spaces, periodic losses in acoustic communication signals and disruption of acoustic navigation beacons are to be expected. The problem becomes more pronounced as the frequency of the signal increases.

Open-circuit SCUBA affects sound reception by producing high noise levels at the diver's head and by creating a screen of bubbles that reduces the effective sound pressure level (SPL). If several divers are working in the same area, the noise and bubbles will affect communication signals more for some divers than for others, depending on the position of the divers in relation to the communicator and to each other.

Since sound travels so fast underwater (3,240 mph or 4,921 feet per second), human ears cannot detect the difference in time of arrival of a sound between each ear. Consequently, a diver loses the ability to locate the direction of a sound source. This disadvantage can have serious consequences for a diver or swimmer in locating objects and sources of danger such as powerboats.

A neoprene wet suit is an effective barrier to sound above 1,000 Hz, and it becomes more of a barrier as frequency increases. This problem can be overcome by exposing a small area of the head either by cutting holes at the ears of the suit or by folding a small flap away from the surface.

Sound is transmitted through water as a series of pressure waves. High intensity sound is transmitted by correspondingly high intensity pressure waves. A diver may be affected by a high pressure wave that is transmitted from the surrounding water to the open spaces within the body (ears, sinuses, lungs). The pressure wave may create increased pressure within these open spaces, causing injury.

The sources of high intensity sound or pressure waves include underwater explosions and, in some cases, sonar. Low intensity sonar such as depth finders and fish finders do not produce pressure waves of an intensity dangerous to divers. However, anti-submarine sonar-equipped ships do pulse dangerously high-intensity pressure waves. It is prudent to suspend diving operations if a high-powered sonar transponder is being operated in the area. When using a diver-held pinger system, divers are advised to wear the standard 1/4-inch neoprene hood for ear protection. Experiments have shown that such a hood offers adequate protection when the ultrasonic pulses are of 4-msec duration, repeated once per second for acoustic source levels up to 100 watts, at head-to-source distances as short as .5 feet (Pence and Sparks, 1978).

2-6.3 Underwater Explosions. An underwater explosion creates a series of waves which propagate (are transmitted) in the water as hydraulic shock waves or the so-called water hammer, and in the seabed as seismic waves. The hydraulic shock wave of an underwater explosion consists of an initial wave followed by further pressure waves of diminishing intensity. The initial high intensity shock wave is the result of the violent creation and liberation of a large volume of gas, in the form of a gas pocket, at high pressure and temperature.

Subsequent pressure waves are caused by rapid gas expansion in a non-compressible environment, causing a sequence of contractions and expansions as the gas pocket rises to the surface.

The initial high intensity shock wave is the most dangerous; it travels outward from the source of the explosion, losing its intensity with distance. The less severe pressure waves follow the initial shock wave very closely. Considerable turbulence and movement of the water in the area of the explosion are evident for an extended time after the detonation.

A number of factors affect the intensity of the shock wave and pressure waves; each should be evaluated in terms of the particular circumstances in which the explosion occurs and the type of explosives involved.

2-6.3.1 Type of Explosive and Size of The Charge. Some explosives have characteristics of high brisance (shattering power in the immediate vicinity of the explosion) with less power at long range, while the brisance of others is reduced to increase their power over a greater area. Those with high brisance generally are used for cutting or shattering purposes, while high power low brisance explosives are used in depth charges and sea mines where the target may not be in immediate contact and the ability to inflict damage over a greater area is an advantage. The high brisance explosives therefore create a high level shock wave and pressure waves of short duration over a limited area. High power explosives create a less intense shock and pressure waves of long duration over a greater area. The characteristics of the explosive need to be evaluated carefully before use to estimate the type and duration of shock and pressure waves. Characteristics to be considered are:

- rate of detonation
- density of loading
- temperature
- chemical structure, i.e., introduction of non-explosive additives to reduce detonation rate
- type of initiator and booster used

2-6.3.2 Characteristics of the Seabed. Aside from the fact that rock or other bottom debris may be propelled through the water or even into the air with shallow-placed charges, bottom conditions may have a dampening or amplifying effect on the shock and pressure waves. A soft bottom tends to dampen reflected shock and pressure waves, while a hard, rock bottom may amplify the effect. The contour of the bottom is an important consideration because rock strata, ridges, and other topographical features may affect the direction of the shock and pressure waves, and may also produce secondary reflecting waves.

2-6.3.3 Location of the Explosive Charge. Research has indicated that the magnitude of shock and pressure waves generated from charges freely suspended in water is considerably greater than that from charges placed in drill holes in rock or coral.

2-6.3.4 Depth of Water. At great depth, the shock and pressure waves are attenuated by the greater water volume, and are thus reduced in intensity. An explosion near the surface is not attenuated to the same degree.

2-6.3.5 Distance from the Explosion. In general, the farther away from the explosion, the greater the attenuation of the shock and pressure waves, and the less the intensity. This factor must be considered in the context of bottom conditions, depth of water, and reflection of shock and pressure waves from underwater structures and topographical features.

2-6.3.6 Degree of Submersion of the Diver. A fully submerged diver receives the total effect of the shock and pressure waves passing over the body. If a diver is submerged only partially, with the head and upper parts of the body out of the water, the effect of the shock and pressure waves on the lungs, ears, and sinuses may be reduced; however, air will transmit some portion of the explosive shock and pressure waves. The head, lungs, and intestines are the parts of the body most vulnerable to the pressure effects of an explosion.

There are various formulas for estimating the pressure wave resulting from an explosion of

T.N.T. That the equations vary in format and result illustrates that the technique for estimation is very tentative. Moreover, these formulas relate to T.N.T. and are not applicable to other types of explosives.

The following formula (Greenbaum and Hoff 1966) is one method of estimating the pressure on a diver resulting from an explosion of tetryl or T.N.T.

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

Where: P = pressure on the diver in pounds per square inch

W = weight of the explosive (tetryl or T.N.T.) in pounds

r = range of the diver from the explosion in feet

A simple calculation shows that a 45-pound charge at a distance of 80 feet exerts a pressure of 578 pounds per square inch. A pressure wave of 500 pounds per square inch is sufficient to cause serious injury to the lungs and intestinal tract, and one greater than 2,000 pounds per square inch will cause certain death. Even a pressure wave of 500 pounds per square inch could cause fatal injury under certain circumstances.

When expecting an underwater blast, the diver shall get out of the water and out of range of the blast whenever possible. If the diver must be in the water, it is prudent to limit the pressure he experiences from the explosion to less than 50 or 70 pounds per square inch. To minimize the effects, the diver also can take up a position with feet pointing toward, and head directly away, from the explosion. The head and upper section of the body should be out of the water, or the diver should float on his back with his head out of the water.

2-6.4 Heat. Heat, or the absence of it, is crucial to man's environmental balance. The human body functions within only a very narrow range of internal temperature, and contains delicate mechanisms to control that temperature (see Chapter 3).

Heat is a form of energy associated with and proportional to the molecular motion of a substance. It is closely related to temperature, but must be distinguished from temperature because different substances do not necessarily contain the same heat energy even though their temperatures are the same.

Temperature is measured in degrees, usually Fahrenheit or Celsius as discussed in Paragraph 2-3. Heat is measured in British Thermal Units (BTUs), calories, or kilo-calories. One BTU is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. A calorie is the amount of heat required to raise the temperature of a gram of water one degree Celsius, and a kilo-calorie is the corresponding amount for a kilogram (1,000 grams) of water.

Heat is generated in many different ways, including the burning of fuels and other chemical reactions, by friction, and by electricity. Heat is transmitted from one place to another in three ways: conduction, convection, and radiation.

Conduction is the transmission of heat by direct contact. A typical example of conduction is the heating of a cooking pot handle. Water is a much better conductor of heat than air, and an unprotected diver can lose a great deal of body heat to the surrounding water by direct conduction.

Convection is the transmission of heat by the movement of heated fluids. This is the principle behind the operation of most home heating systems, which set up a flow of air currents based on the natural tendency of warm air to rise and cool air to fall. A diver, seated on the bottom of a tank of water in a cold room, can lose heat not only by direct conduction to the water, but also by convection currents in the water. The warmed water next to his body will rise and be replaced by colder water passing along the walls of the tank, or reaching the surface, will lose heat to the cooler surroundings. Once cooled, the water will sink only to be warmed again as part of a continuing cycle.

Radiation is the transmission of heat by electromagnetic waves of energy. Heat from the sun, from electric heaters, and from fireplaces is primarily radiant heat.

Of the three means of transmitting heat, conduction is the most significant to divers. The rate at which heat will be transferred by conduction depends on two basic factors:

(1) the difference in temperature between the warmer and cooler material

(2) the thermal conductivity of the materials

Some substances such as iron, helium, and water are excellent conductors of heat. Some, like air, are very poor conductors. A poor conductor, if placed between a source of heat and another substance, will insulate the substance and appreciably slow the transfer of heat. Most of the materials used for insulation of the human body such as wool and foam rubber, are effective because they contain thousands of pockets of trapped air, each too small to be subject to convective currents but each blocking conductive transfer of heat.

A diver's experience with temperatures in the home does not give him a basis with which to evaluate the heat problems encountered underwater. The water temperature below which a diver will start to become chilled is a seemingly comfortable 70°F (21°C). Below that temperature, a diver wearing only a swimming suit will lose heat to the water faster than his body can replace it, and unless he is provided some protection or insulation, he may soon experience difficulties. A diver who is chilled cannot work efficiently, or think clearly, and is more susceptible to decompression sickness.

Several factors contribute to the problem of maintaining a diver's body temperature, including suit compression, increased gas density, thermal conductivity of breathing gases, and respiratory heat loss. The cellular neoprene wet suit loses a major portion of its insulating property as depth increases and the material is compressed. As a consequence, it is often necessary to employ a thicker suit, a dry suit, or a hot water suit for extended exposures to cold water.

The heat transmission characteristics of a gas are directly proportional to its density. Therefore, the heat lost through gas insulating barriers and respiratory heat lost to the surrounding areas increases with depth. This situation is further aggravated when high thermal conductivity gases, such as helium-oxygen, are used for breathing. The respiratory heat loss alone increases from 10 percent of the body's heat generating capacity at one ata, to 28 percent at seven ata, to 50 percent at 21 ata when breathing helium-oxygen. Under these circumstances, insulating materials are insufficient to maintain body temperatures, and supplementary heat (usually hot water) must be supplied to the body surface and respiratory gas.

2-7 SUMMARY

The principles of physics discussed in this chapter provide the keystone to understanding the reasons for using various techniques, procedures, and equipment in conducting diving operations. They also are of particular significance in studying the effects of the underwater environment upon the human body.

CHAPTER THREE

UNDERWATER PHYSIOLOGY

3-1 INTRODUCTION

Physiology is the study of the processes and functions of the body. Anatomy is the study of the structure of the organs of the body. When conditions in 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 of the organs and systems. The heart pumps blood to all parts of the body, the tissue fluids exchange dissolved materials with the blood, and the lungs keep the blood supplied with oxygen and cleared of excess carbon dioxide. Most of these processes are controlled directly by the brain, nervous system, and various glands. For the most part, the individual is unaware that these functions are taking place.

The body 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. Such external effects set definite limits on what a diver can do, and they can give rise to serious accidents. Safe diving is possible only through knowing what physiological effects are produced, how much of a limit they impose, and how some of them can be avoided or reduced. Divers need to have a basic understanding of the body and its vital processes so that they will respect the increased demands imposed on the body by the underwater environment. A diver's knowledge is as important as his own good health and the condition of his gear. This chapter presents a general discussion of human anatomy and physiology and the effects of diving on the body.

3-2 THE BODY SYSTEMS

The body's tissues and organs are organized into various systems, each with a specific job to do. The musculoskeletal, nervous, circulatory, and respiratory systems are of primary concern to divers. The remaining body systems (digestive, excretory, and endocrine) are seldom affected by the demands of the underwater environment and are not discussed in this chapter.

3-2.1 The Musculoskeletal System. The skeletal system provides the frame that gives strength to the body and protection to the vital organs. Muscles make the body move and offer protection to the vital organs.

3-2.2 The Nervous System. The nervous system coordinates all body functions and activities. It contains the brain, spinal cord, and a complex network of nerves which course through the body. The brain and spinal cord are collectively referred to as the Central Nervous System (CNS). Nerves that originate in the brain and spinal cord and travel to peripheral parts of the body form the peripheral nervous system. This system consists of the cranial nerves, the spinal nerves, and the sympathetic nervous system. The peripheral nervous system is involved in regulating cardiovascular, respiratory, and other automatic body functions. These nerve trunks also transmit nerve impulses associated with sight, hearing, balance, taste, touch, pain, and temperature between peripheral sensors and the spinal cord and brain.

3-2.3 The Circulatory System. The circulatory system consists of the heart, arteries, veins, and capillaries. Its function is to bring oxygen, nutrients, and hormones to every cell of the body and to carry away carbon dioxide, waste chemicals, and heat. The circulatory system is discussed in Paragraph 3-3.

3-2.4 The Respiratory System. The respiratory system consists of the lungs and associated air passages. Its function is to bring oxygen into the body and to expel carbon dioxide. The respiratory system is discussed in Paragraph 3-4.

3-3 CIRCULATION

The circulation of blood throughout the body transports respiratory gases and body nutrients. Circulation occurs through a closed system of tubes which includes the lung and tissue capillaries, heart, arteries, and veins.

3-3.1 Anatomy. The very large surface areas required for ample diffusion of gases in the lungs and 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 of capillaries. In the lungs, these capillaries surround the tiny air sacs (alveoli) so that the blood they carry can exchange gases with air.

The heart (Figure 3-1) is the muscular pump that propels the blood throughout the system. It is about the size of a closed fist, hollow, and made up almost entirely of muscle tissue which forms its walls and provides the pumping action. It is located in the front and center of the chest cavity between the right and left lungs, directly behind the breastbone (sternum).

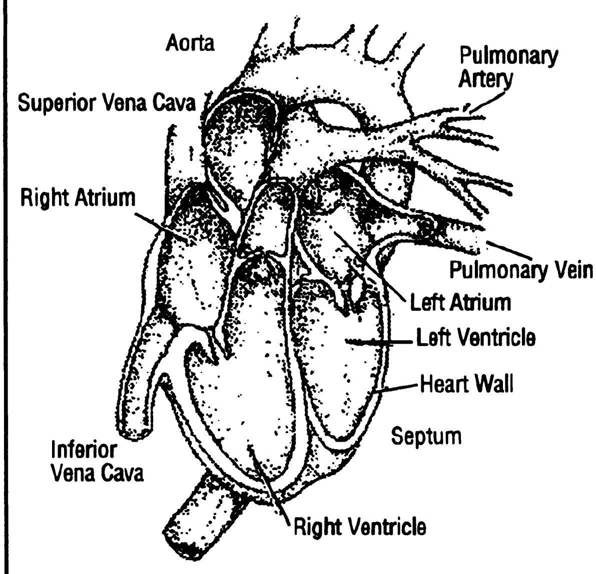


Figure 3-1. The Heart's Components and Blood Flow.

The interior of the heart is divided lengthwise into two halves, separated by a wall of tissue called a septum, that have no direct conduit to each other. Each half is divided into an upper chamber (the atrium), which receives blood from the veins of its circuit, and a lower chamber (the ventricle) which takes blood from the atrium and pumps it away via the main artery. Because the ventricles do most of the pumping, they have the thickest, most muscular walls. The arteries carry blood from the heart to the capillaries; the veins return blood from the capillaries to the heart. Arteries and veins branch and rebranch many times, very much like a tree. Trunks near the heart are approximately the diameter of a human thumb, while the smallest arterial and venous twigs are microscopic. Capillaries provide the connections that let blood flow from the smallest branch arteries (arterioles) into the smallest veins (venules).

Although it forms a continuous closed circuit of tubes with the same blood flowing throughout, the circulatory system actually consists of two circuits. The pulmonary circuit serves the lung capillaries; the systemic circuit serves the tissue capillaries. Each circuit has its own arteries and veins and its own half of the heart as a pump. Figure 3-2 shows how the system is arranged. In complete circulation, blood first passes through one circuit and then the other, going through the heart twice in each complete circuit.

3-3.2 Circulatory Function. Blood follows a continuous circuit through the human body. Blood leaving a capillary in muscle, or in one of the organs, has lost most of its oxygen and is loaded with carbon dioxide. The blood flows into larger and larger veins until it reaches the

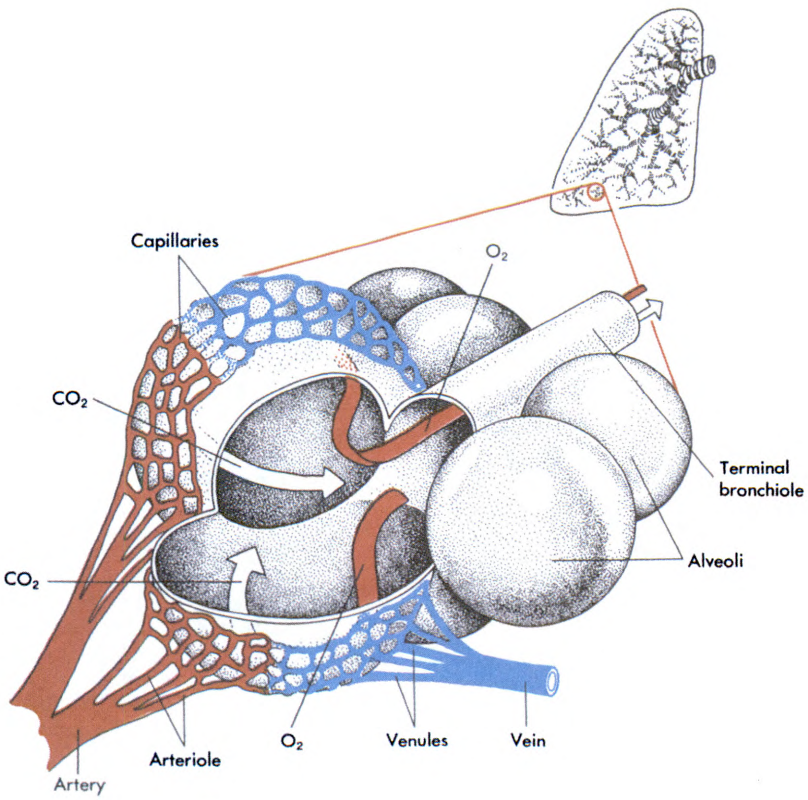


Figure 3-2. Respiration and Blood Circulation. The lung's gas-exchange system is essentially three pumps. The thorax, a gas pump, moves air through the trachea and bronchi to the lung's air sacs. These sacs, the alveoli, are shown with and without their covering of pulmonary capillaries. The heart's right ventricle, a fluid pump, moves blood which is low in oxygen and high in carbon dioxide, into the pulmonary capillaries. Oxygen from the air diffuses into the blood while carbon dioxide diffuses from the blood into the air in the lungs. The oxygenated blood moves to the left ventricle, another fluid pump, which sends the blood to the systemic capillaries which deliver oxygen to and collect carbon dioxide from the body's cells.

main veins in the upper chest (the superior and inferior vena cava). The superior vena cava receives blood from the upper half of the body; the inferior vena cava receives blood from areas of the body below the diaphragm. From there, blood flows into the right atrium and then through the tricuspid valve into the right ventricle. The next contraction of the heart forces the blood through the pulmonic valve into the pulmonary artery. The blood then goes through the arterial branchings of the lungs into the pulmonary capillaries, where gas transfer with air takes place. By diffusion, the blood exchanges inert gas as well as carbon dioxide and oxygen with the air in the lungs. The blood then returns to the heart via the pulmonary venous system and enters the left atrium. The next relaxation finds it going through the mitral valve into the left ventricle to be pumped through the aortic valve into the main artery (aorta) of the systemic circuit. The blood then flows through the arteries branching from the aorta, then successively smaller vessels until it reaches the capillaries, where it exchanges oxygen for carbon dioxide. It is now ready for another trip to the lungs and back again.

The larger blood vessels are somewhat elastic and have muscular walls. They stretch as blood is ejected from the heart with each beat, and contract between beats to maintain a slow but adequate flow (perfusion) through the capillaries. Stresses during diving, such as excessive urine formation (immersion diuresis), decompression sickness, shock, and gas embolism, can affect blood flow.

3-3.2.1 Blood Components. An average person's body contains about five liters of blood. Oxygen is carried mainly in the red corpuscles (red blood cells). There are approximately 300 million red corpuscles in an average-sized drop of blood. These corpuscles are small, disc-shaped cells that contain hemoglobin to carry oxygen. Hemoglobin is a complex chemical compound containing iron. It can form a loose chemical combination with oxygen, soaking it up almost as a sponge soaks up liquid. Hemoglobin is bright red when it is oxygen-rich; it becomes increasingly bluish as it loses oxygen. Hemoglobin gains or loses oxygen depending upon the partial pressure of oxygen to which it is exposed. Hemoglobin takes up about 98 percent of the oxygen it can carry when it is exposed to the normal partial pressure of oxygen in the lungs. Because the cells are using oxygen, the partial pressure (tension) in the tissues is much lower, and the hemoglobin gives up much of its oxygen in the tissue capillaries.

Acids form as the carbon dioxide dissolves in the blood. Buffers in the blood neutralize the acids and permit large amounts of carbon dioxide to be carried away to prevent excess acidity. Hemoglobin plays an important part in transporting carbon dioxide and in carrying oxygen. The uptake or loss of carbon dioxide by blood depends mainly upon the partial pressure (or tension) of the gas in the area where the blood is exposed. For example, in the peripheral tissues, carbon dioxide diffuses into the blood and oxygen diffuses into the tissues.

In addition to red blood cells, the blood also contains white blood cells, which serve to fight infections, and platelets, which are cells essential in blood coagulation. Plasma is the watery, colorless fluid portion of the blood. It contains a large amount of dissolved material essential to life. The blood also contains several substances, such as fibrinogen, associated with blood clotting. Without the clotting ability, death could result from even the slightest injury. Decompression sickness can initiate clotting, in part because bubbles can act as foreign bodies in the vascular system.

3-4 RESPIRATION

Every cell in the body must obtain energy to maintain its life, growth, and function. The cells obtain this energy from oxidation, which is a slow, controlled burning of food materials. As with the burning of any material, oxidation requires fuel and oxygen. Respiration is the process of exchanging oxygen and carbon dioxide during oxidation and releasing energy and water.

Few of the body's billions of cells are close enough to the surface of the body to have any chance of obtaining oxygen and expelling carbon dioxide by direct air diffusion. 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 capillary vessels 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 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.

If the membrane surface in the lung, where blood and air come close together, were just an exposed sheet of tissue like the skin, natural air currents would keep fresh air in contact with it. Actually, this lung membrane surface is many times larger than the skin area and is folded and compressed into the small space of the lungs which are protected inside the bony cage of the chest. This makes it necessary to continually move air in and out of the space continually. The process of breathing and the exchange of gases in the lungs is referred to as external respiration to distinguish it from the use, production, and exchange of gases that takes place in the tissues, which is referred to as internal respiration.

The complete process of respiration includes six important phases:

(1) Ventilation of the lungs with fresh air (Breathing)

(2) Exchange of gases between blood and air in lungs (Diffusion)

(3) Transport of gases by blood

(4) Exchange of gases between blood and tissue fluids (Diffusion)

(5) Exchange of gases between the tissue fluids and cells (Diffusion)

(6) Use and production of gases by cells (Metabolism)

If any one of these processes stops or is seriously hindered, the affected cells can no longer function normally or survive for any length of time. Brain tissue cells, for example, will stop working almost immediately and will either die or be permanently injured in a few minutes if their oxygen supply is completely cut off. These vital processes, and the respiratory and circulatory systems that carry them out, are important aspects of the physiological effects of diving.

The respiratory system is a complex of organs and structures that performs the pulmonary ventilation of the body and the exchange of oxygen and carbon dioxide between the ambient air and the blood circulating through the lungs. It also warms the air passing into the body and assists in the speech function by providing air to the larynx and the vocal chords. The respiratory tract is divided into upper and lower tracts.

3-4.1 Upper Respiratory Tract. The upper respiratory tract consists of the nose, nasal cavity, frontal sinuses, maxillary sinuses, larynx, and trachea. The upper respiratory tract carries air to and from the lungs; and filters, moistens, and warms air during each inhalation.

3-4.2 Lower Respiratory Tract. The lower respiratory tract consists of the left and right bronchi, and the lungs, where the exchange of oxygen and carbon dioxide occurs during the respiratory cycle. The bronchi divide into smaller bronchioles in the lungs, the bronchioles divide into alveolar ducts, the ducts into alveolar sacs, and the sacs into alveoli. The alveolar sacs and the alveoli present about 850 square feet of space for the exchange of oxygen and carbon dioxide that occurs between the internal alveolar surface and the tiny capillaries surrounding the external alveolar wall.

3-4.3 The Respiratory Apparatus. The mechanics of taking fresh air into the lungs (inspiration or inhalation) and expelling used air from the lungs (expiration or exhalation) is diagrammed in Figure 3-3. By elevating the ribs and lowering the diaphragm, the volume of the lung is increased. Thus, according to Boyle's Law, a lower pressure is created within the lungs and fresh air rushes in to equalize this lowered pressure. When the ribs are lowered again and the diaphragm rises to its original position, a higher pressure is created within the lungs, causing the used air to be expelled.

The human chest cavity does not have space between the outer lung surfaces and the surrounding chest wall and diaphragm. Both surfaces are covered by membranes; the visceral pleura covers the lung, and the parietal pleura lines the chest wall. These pleurae are separated from each other by a small amount of fluid that acts as a lubricant to allow the membranes to slide freely over themselves as the lungs expand and contract during respiration.

The lungs are a pair of light, spongy organs in the chest and they constitute the main component of the respiratory system. The highly elastic lungs are the main mechanism in the body for inspiring air from which oxygen is extracted for the arterial blood system, and for exhaling carbon dioxide dispersed from the venous system. The lungs are composed of lobes that are smooth and shiny on their surface. The lungs contain millions of small expandible air sacs (alveoli) connected to air passages. These passages branch and rebranch like the twigs of a tree. Air that enters into the main airways of the lungs gains access to the entire surface of these alveoli. Each alveolus is lined with a thin membrane and is surrounded by a network of very small blood vessels. These blood vessels make up the

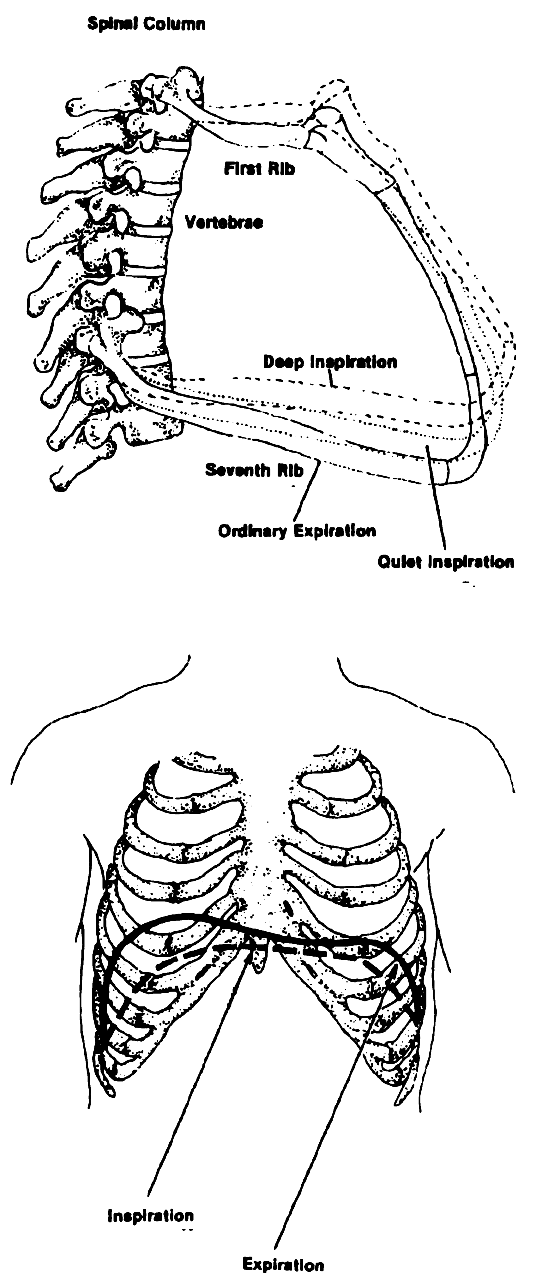


Figure 3-3. Inspiration Process. Inspiration involves both raising the rib cage (top panel) and lowering the diaphragm (lower panel). Both movements enlarge the volume of the thoracic cavity and draw air into the lung.

capillary bed of the lungs. Most of the lung membrane has air on one side of it and blood on the other; diffusion of gases takes place freely in either direction (see Figure 3-4).

3-4.4 Respiratory Tract Ventilation. Ventilation of the respiratory system is important in establishing the proper composition of gases in the alveoli for exchange with the blood. The following definitions help in understanding respiration (Figure 3-5).

- Respiratory Cycle - One complete breath consisting of an inspiration and exhalation, including any pause that may occur between the movements.

- Respiratory Rate - The number of complete respiratory cycles that take place in one minute. At rest, a normal adult will have a respiratory rate of approximately 12 to 16 breaths per minute.

- Total Lung Capacity (TLC) - The total volume of air that the lungs can hold when filled to capacity. It is normally between five and six liters.

- Vital Capacity - The volume of air that can be expelled from the lungs after a full inspiration. The average vital capacity is between four and five liters.

- Tidal Volume - The volume of air moved in or out during a single normal respiratory cycle. At rest, the tidal volume generally averages about one-half liter. Tidal volume increases considerably during physical exertion. It naturally cannot exceed the vital capacity.

- Respiratory Minute Volume (RMV) - The total amount of air moved in or out of the lungs in a minute. Multiplying the tidal volume by the rate gives the respiratory

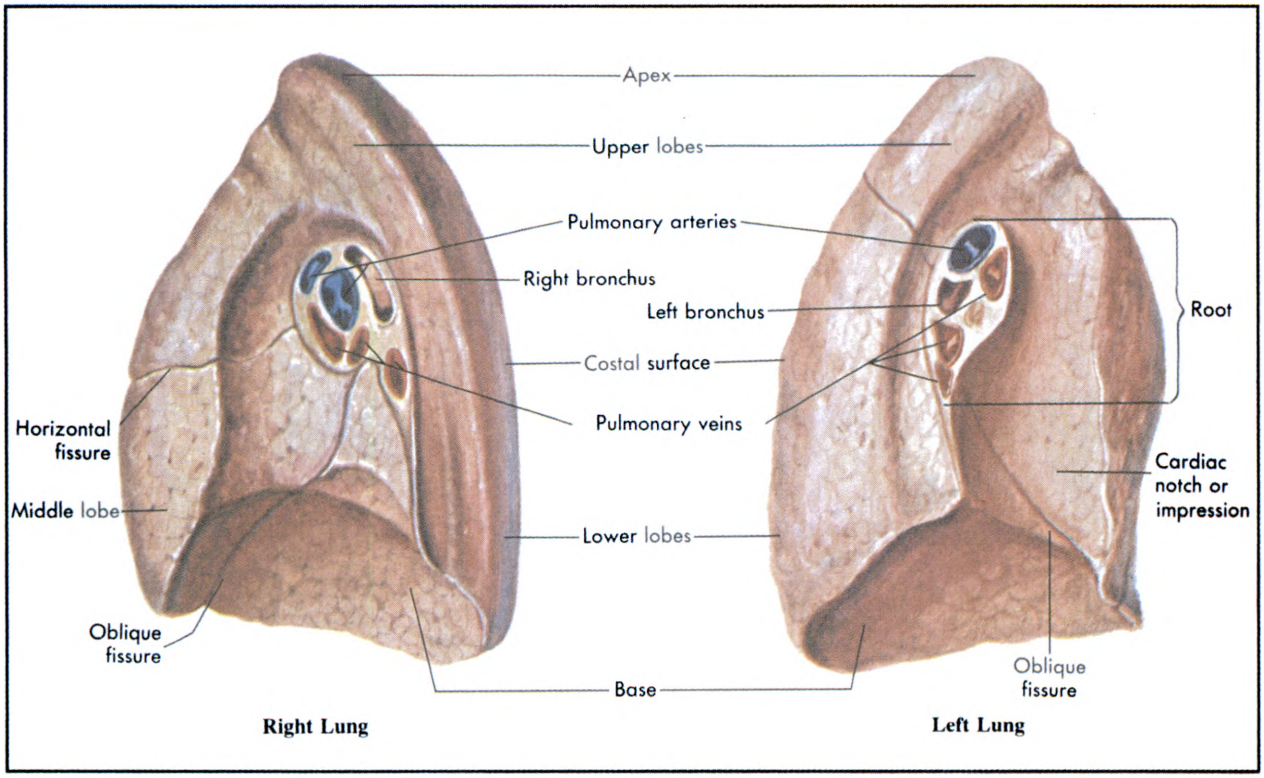


Figure 3-4. Lungs Viewed from Medial Aspect.

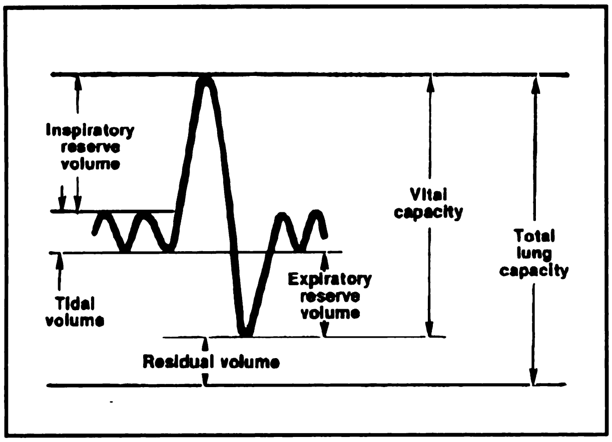


Figure 3-5. Lung Volumes. The heavy line is a tracing derived from a subject breathing to and from a sealed recording bellows. Following several normal tidal breaths, he inhalesmaximally, then exhales maximally. The volume of air moved during this maximal effort is called the vital capacity. During excercise, the tidal volume increases, using part of the inspiratory and expiratory reserve volumes. The tidal volume, however, can never exceed the vital capacity. The residual volume is the amount of air remaining in the lung after the most forceful expiration. The sum of the vital capacity and the residual volume is the total lung capacity.

minute volume. RMV varies greatly with the body's activity. It is about 6 to 10 liters per minute at complete rest and may be over 100 liters per minute during severe work.

- Maximal Breathing Capacity (MBC) or Maximum Ventilatory Volume (MVV) - The greatest respiratory minute volume that a person can produce during a short period of extremely forceful breathing. In a healthy young man, it may average as much as 100 liters per minute.

- Maximum Inspiratory Flow Rate (MIFR) and Maximum Expiratory Flow Rate (MEFR) - The fastest rates at which the body can move gases in and out of the lungs. These rates are important in designing breathing equipment and computing gas use under various workloads. Such terms are usually expressed in liters per second.

- Respiratory Quotient (RQ) - A term frequently used to express the ratio of the amount of carbon dioxide produced to the amount of oxygen consumed per unit time. This value ranges from 0.7 to 1.0 depending on diet and physical exertion and is usually assumed to be 0.9 for calculations. This relationship is significant when calculating the carbon dioxide that will be produced as oxygen is used at various workloads while using a closed-circuit breathing system apparatus. The duration of the carbon dioxide absorbent canister can then be compared to the duration of the oxygen supply.

- Respiratory Dead Space - The part of the respiratory system that 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. Air that occupies the dead space at the end of expiration is rebreathed in the following inspiration. Certain 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 that serves the purpose of respiration. To compensate, the diver must increase his tidal volume. The problem can best be visualized by using a breathing tube as an example. If the tube contains one liter of air, a normal exhalation of about one liter will leave the tube filled with used air from the lungs. At inhalation, the used air will be drawn right back into the lungs. The tidal volume must be increased by more than a liter to draw in the needed fresh supply, because any fresh air is diluted by the air in the dead space. Thus it can be seen that the air that is taken into our lungs (inspired air) is a mixture of fresh and dead space gases.

3-4.4.1 Alveolar/Capillary Gas Exchange. Within the alveolar air spaces, the composition of the air (alveolar air) is changed by the elimination of carbon dioxide from the blood, the absorption of oxygen by the blood, and the addition of water vapor. The air that is exhaled is a mixture of alveolar air and the inspired air that remained in the dead space.

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 pressure of the blood leaving the lungs is approximately equal to that present in alveolar air. This arterial blood passes through the capillary network surrounding the cells in the body tissues it is exposed to and equalizes with the gas pressure of the tissues. Some of the blood's oxygen is consumed by the cells, and carbon dioxide is picked up from these cells. 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, lowering its pressure, and oxygen is absorbed by the blood from the alveolar air, increasing its pressure. With each complete round of circulation, the blood is the medium through which this process of gas exchange occurs. Each cycle normally requires approximately 20 seconds.

3-4.5 Control of Breathing. The amount of oxygen consumed and carbon dioxide produced increases markedly when a diver is working. The amount of blood being pumped through the tissues and the lungs per minute 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 maintain proper blood levels, the respiratory minute volume must also change in proportion to oxygen consumption and carbon dioxide output.

Changes in the concentration of oxygen and carbon dioxide (ppO_2 and $ppCO_2$) in the arterial circulation activate central and peripheral chemoreceptors. These chemoreceptors are attached to important arteries. The most important are the carotid bodies in the neck and aortic bodies near the heart. The chemoreceptor in the carotid artery is activated by the $ppCO_2$ in the blood, and signals the respiratory center in the brain stem near the origin of the spinal cord to increase or decrease respiration. The chemoreceptor in the aorta causes the aortic body reflex. This is a normal chemical reflex initiated by decreased oxygen concentration and increased carbon dioxide concentration in the blood. These changes result in nerve impulses that increase respiratory activity. Low oxygen tension alone does not increase breathing markedly until dangerous levels are reached. The part played by chemoreceptors is evident in normal processes such as breathholding.

As a result of the regulatory process and the adjustments they cause, the arterial blood leaving the lungs usually has about the same oxygen and carbon dioxide levels during work that it did at rest. The maximum pumping capacity of the heart (blood circulation) and respiratory system (ventilation) largely determines the amount of work a person can do.

3-4.5.1 Oxygen Consumption. A diver's oxygen consumption is an important factor when determining how long breathing gas will last, the ventilation rates required to maintain proper helmet oxygen level, and the length of time a canister will absorb carbon dioxide (CO_2). Oxygen consumption is a measure of energy expenditure and is closely linked to the respiratory processes of ventilation and CO_2 production.

Oxygen consumption is measured in liters per minute (l/min) at Standard Temperature and Pressure, Dry Gas (STPD); the rates for different levels of activity are given in Figure 3-6. These rates of oxygen consumption are not

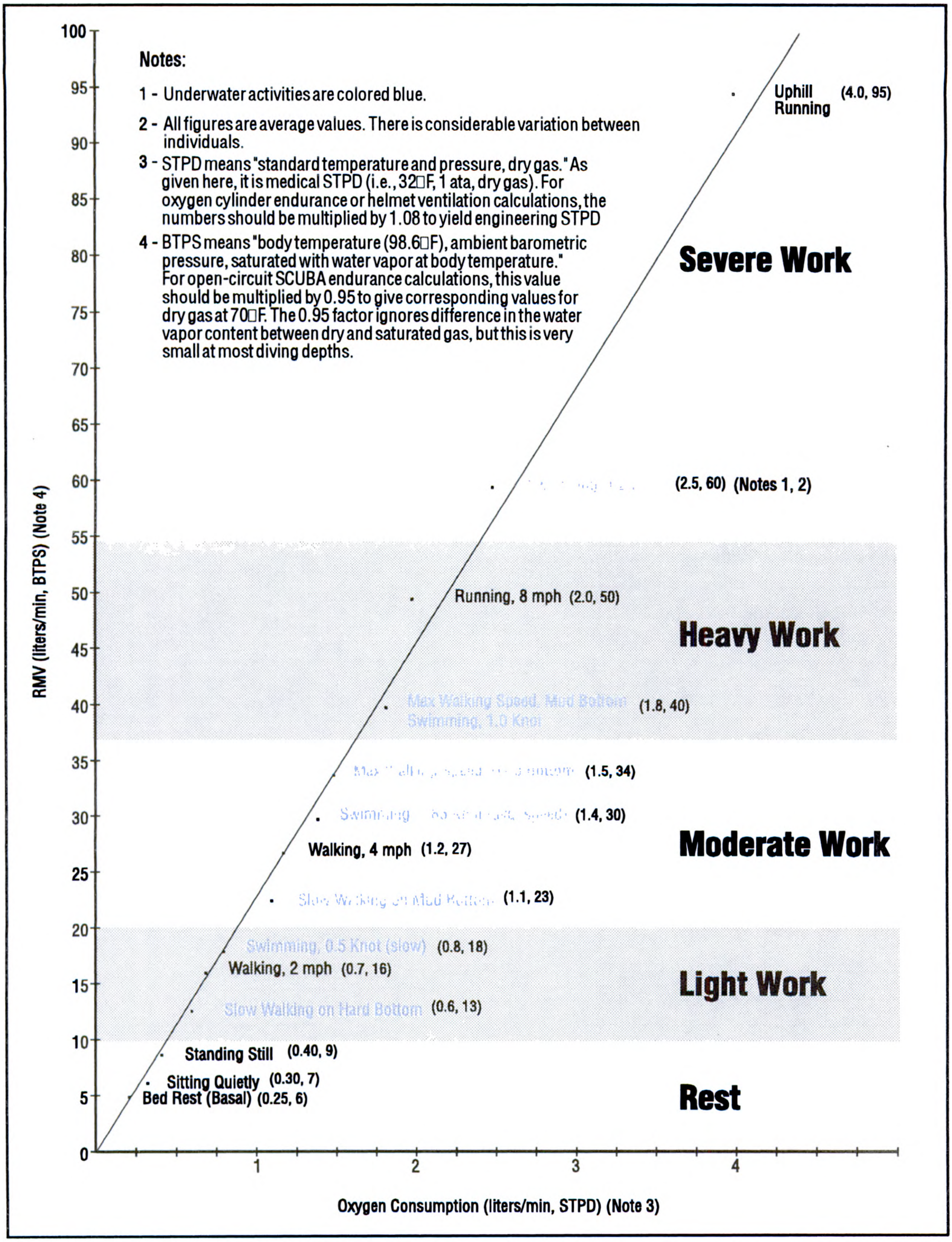


Figure 3-6. Oxygen Consumption and RMV at different Work Rates.

depth dependent. This means that a fully charged MK 16 oxygen bottle which contains 360 standard liters (3.96 scf) of useable gas will last 225 minutes at an oxygen consumption rate of 1.6 l/min at any depth, provided no gas leaks from the rig.

Minute ventilation, or Respiratory Minute Volume (RMV), is measured at BTPS (body temperature (98.6°F), ambient barometric pressure, saturated with water vapor at body temperature) and varies depending on a person's activity level, as shown in Figure 3-6. At the surface, RMV can be approximated by multiplying the oxygen consumption rate by 25. Although this 25:1 ratio decreases with increasing gas density and high inhaled oxygen concentrations, it is a good rule-of-thumb approximation for computing how long the breathing gas will last.

Unlike oxygen consumption, the amount of gas exhaled by the lungs is depth dependent. At the surface, a diver swimming at 0.5 knot exhales 20 l/min of gas. A SCUBA cylinder containing 71.2 standard cubic feet (scf) of air (approximately 2,000 standard liters) lasts approximately 100 minutes. At 33 fsw, the diver still exhales 20 l/min at BTPS, but the gas is twice as dense; thus, the exhalation would be approximately 40 standard l/min, and the cylinder would last only half as long, or 50 minutes. At three atmospheres, the same cylinder would last only one third as long as at the surface.

The ratio of CO_2 production to oxygen consumption is called the Respiratory Quotient (RQ) and, depending on diet or physical exertion, ranges from 0.7 to 1.0. However, 0.9 is a good rule-of-thumb value for making calculations. CO_2 production depends only on the level of exertion and can be assumed to be independent of depth. CO_2 production and RQ are used to compute ventilation rates for chambers and diving helmets such as the MK 12 (air mode). These factors may also be used to determine whether the oxygen supply or the duration of the CO_2 absorbent will limit a diver's time in a closed or semi-closed system (refer to Paragraph 3-4.6).

3-4.6 Breathing Equipment Considerations. Oxygen consumption is used to compute the oxygen flask duration in closed-circuit UBAs, 100-percent oxygen rebreathers, and the ventilation rates required to maintain proper helmet oxygen level in semi-closed breathing apparatus such as the MK 12 helium-oxygen rig. Respiratory Minute Volume (RMV) is used to compute gas duration or consumption in demand type UBAs such as open-circuit SCUBA or the MK 21 in the demand mode.

Carbon dioxide production at various workloads can be computed from the Respiratory Quotient and used to compute helmet ventilation rates in rigs such as the MK 12 air mode. Exhaled gas containing carbon dioxide is mixed with helmet gas before being washed out by incoming gas. Thus, a certain amount of exhaled cabon dioxide is rebreathed. In calculating helmet ventilation rates, the goal is to keep the level of inspired carbon dioxide below 1.5 percent Surface Equivalent Value (SEV), which is equialent to 11.4 mmHg. If this goal is met, more than enough oxygen is present in the gas in the helmet to meet metabolic needs at any level of exercise. The minimum helmet ventilation needed to keep the inspired carbon dioxide from exceeding 11.4 mmHg is:

$$\textit{Helmet Ventilation (ACFM)} = \frac{28.90 \times CO_2\,\textit{production}\ (l/_{\min}\ STPD)}{11.4\ mmHg}$$

Where:

ACFM = Actual Cubic Feet per Minute

28.90 = Units Conversion Factor

STPD = Standard Temperature and Pressure, Dry Gas (32°F, 1 ata)

CO_2 = 0.9 x oxygen utilization at a given workload

11.4 mmHg = Maximum allowable CO_2 in helmet

The units conversion factor converts mmHg to a fractional concentration, liters to cubic feet and volumes at actual temperature (assumed to be 20°C) to standard temperature (0°C). This factor is computed as follows:

$$28.90 = \frac{760\ mmHg}{28.32\ l/cubic foot} \times \frac{(273 + 20)\ K}{273\ K}$$

The temperature must be converted from 0°C to absolute temperature. If the ventilation formula is used for computing rates at much higher temperatures, then a new conversion factor shall be computed by replacing the 20°C with the appropriate temperature.

This formula for computing helmet ventilation rates does not depend on the helmet volume. This same equation can be used to compute ventilation rates for chambers where occupants are breathing chamber atmosphere. For example, a diver swimming at 0.5 knots would have an oxygen consumption of 0.8 l/min and his carbon dioxide production would be 0.72 l/min. The required helmet ventilation would be 1.8 acfm. Note that the volume of gas consumed in ventilating the helmet is both depth and exercise dependent. The gas consumption above would be approximately 1.8 standard cubic feet per minute (scfm) at the surface but would triple to 5.4 scfm at 66 fsw. If the diver reduced his carbon dioxide production by one half by standing still, the required ventilation rate at any depth would be reduced by one half. This latter point is very important. If a MK 12 diver reduced his air supply for better communications while at rest, the helmet rate might be insufficient to maintain helmet ventilation CO_2 levels during exercise. If the ventilation rate was not increased before beginning exercise, the inspired carbon dioxide level would increase and the diver might begin to suffer signs of carbon dioxide intoxication.

In designing and evaluating breathing apparatus, it is naturally desirable to develop equipment with the least possible dead space. Most current breathing equipment does not have much dead space but certain full face masks can have one-half liter or more. The amount of exhaled air which a rig will return to the lungs on inhalation (the effective dead space volume) cannot be determined by looking at a circuit and measuring the volume of parts which appear to be dead. When evaluating equipment, effective dead space is measured with a machine which simulates breathing and determines how much exhaled gas is actually taken back with each breath.

Breathing is more difficult at depth because the number of molecules packed into a given volume of gas (density) is increased in direct proportion to the absolute pressure. For example, the air breathed at 100 fsw (4.0 ata) is approximately four times as dense as the air at the surface. Even moving air through the respiratory passages inside the body requires about twice as much effort at 100 fsw as at the surface, and the maximum breathing capacity is noticeably reduced. If open-circuit SCUBA is being used at 100 fsw, each breath involves pulling four times as many molecules through the demand regulator. The regulator must be able to handle such increased flows without increasing the work of breathing to the diver. In poorly designed or improvised equipment, the extra effort required for breathing at depth will be quite noticeable and possibly limiting. The diver will increasingly be aware that the rig will not furnish air as rapidly as desired (inadequate Respiratory Minute Volume and/or inadequate maximum flow rate) and that he is experiencing an excess of carbon dioxide (hypercapnia). Divers refer to this as "overbreathing the rig".

3-5 RESPIRATORY PROBLEMS IN DIVING

Physiological problems often occur because divers are underwater and exposed to the pressures of depth. However, some of the difficulties related to respiratory processes can occur at any time because of an inadequate supply of oxygen or inadequate removal of carbon dioxide from the tissue cells. Depth may modify these problems for the diver, but the basic difficulties remain the same.

Fortunately, the diver has normal physiological reserves to adapt to environmental changes and he is only marginally aware of small changes. The extra work of breathing reduces the overall ability to do heavy work at depth, but moderate work can be done with adequate equipment at the maximum depths currently achieved in diving.

3-5.1 Hypoxia. Hypoxia is an abnormal deficiency of oxygen in the arterial blood that causes the tissue cells to be unable to receive sufficient oxygen to maintain normal function. The causes of oxygen deficiency vary, but all involve interference with the normal oxygen supply to the body.

For divers, interference of oxygen delivery can be caused by equipment problems such as low partial pressure of oxygen in the breathing mix, inadequate gas flow, inadequate purging of breathing bags in a closed or semiclosed breathing apparatus, or failure of injectors when using a semiclosed surface supplied diving system. Blockage of all or part of the pulmonary system air passages by vomitus, secretions, water, foreign objects or pneumomediastinum can lead to hypoxia. Interference with ventilation of the lungs can result from pneumothorax or paralysis of the respiratory muscles from spinal cord injury. Oxygen exchange can be decreased at the alveoli/capillary membrane by accumulation of fluid in the tissues (edema), a mismatch of blood flow and alveolar ventilation, lung damage from near-drowning or smoke inhalation, or by "chokes" or bronchospasm from lung irritation secondary to showers of bubbles in the circulation. Interference with blood transportation of oxygen can lead to hypoxia as a result of anemia, carbon monoxide poisoning, or inadequate blood flow. Hypoxia can occur from an interference with gas exchange at the capillary/tissue areas by edema. Interference with oxygen utilization can also occur at the cellular level in such conditions as carbon monoxide poisoning.

Severe hypoxia can result from hyperventilation followed by breathholding. Hyperventilation lowers the CO_2 level in the body below normal, a condition known as hypocapnia, and it may prevent the control mechanism that stimulates breathing from responding until O_2 tension has fallen below the level necessary to maintain consciousness. Extended breathholding after hyperventilation is not a safe procedure. During the longer breathhold, the diver's oxygen level can fall to a low value before he realizes that he must return to the surface and resume breathing. The oxygen level is lowered because exertion not only causes oxygen to be consumed faster, but decreases sensitivity of the CO_2 breakpoint mechanism. This permits the O_2 level to go lower than it would otherwise. When the diver ascends, the drop in oxygen partial pressure in the lungs may be sufficient to stop further uptake of oxygen completely. At the same time, the partial pressure of CO_2 in the lungs also drops, giving the diver the false impression that he need not breathe.

3-5.1.1 Symptoms of Hypoxia. Severe 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 prominent. If hypoxia develops gradually, symptoms of interference with brain function will appear. Symptoms of hypoxia include:

- Lack of concentration
- Lack of muscle control
- Inability to perform delicate or skill-requiring tasks
- Drowsiness
- Weakness
- Loss of consciousness

The partial pressure of oxygen determines whether the amount of oxygen in a breathing medium is adequate. For example, air contains about 21 percent oxygen and thus provides an oxygen partial pressure of about 0.21 ata at the surface. This is ample, but a drop to 0.14 ata will cause the onset of hypoxic symptoms on the surface. If the ppO_2 goes as low as 0.11 ata at the surface, most individuals will become hypoxic to the point of being nearly helpless. Consciousness is usually lost at about 0.10 ata, and at much below this level, permanent brain damage and death will probably result. In diving, a lower percentage will suffice as long as the total pressure is sufficient to maintain an adequate ppO_2. For example, five-percent oxygen would render a ppO_2 of 0.20 ata for a diver at 100 fsw. On ascent, however, the diver would rapidly experience hypoxia if the oxygen percentage was not increased.

When hypoxia develops, pulse rate and blood pressure increase as the body tries to offset the hypoxia by circulating more blood. A small increase in breathing may also occur. None of these symptoms, however, are sufficient warning, and very few people are able to recognize the mental effects of hypoxia in time to take corrective action.

A general blueness (cyanosis) of the lips, nail beds and skin may occur with hypoxia. This may not be noticed by the diver and often is not a reliable indicator of hypoxia, even for the trained observer at the surface. The same signs could be caused by prolonged exposure to cold water.

There is no reliable warning of the onset of hypoxia. It can occur unexpectedly, making it a particularly serious hazard. A diver who loses his air supply is in danger of hypoxia, but he immediately knows he is in danger, and usually has time to do something about it. He is much more fortunate than a diver who gradually uses up the oxygen in a closed-circuit rebreathing rig and has no warning of impending unconsciousness.

In open-circuit SCUBA and helmets, hypoxia is unlikely unless the supply gas has too low an oxygen content. In closed and semiclosed-circuit Underwater Breathing Apparatus (UBA), a malfunction can cause hypoxia even though the proper gases are being used. These types of UBA usually have oxygen sensors to read out oxygen partial pressure, but divers must be constantly alert to the possibility of hypoxia from UBA malfunction.

3-5.1.2 Prevention of Hypoxia. Because of its insidious nature and potentially fatal outcome, prevention of hypoxia is essential. On mixed-gas operations, strict attention must be paid to gas analysis, cylinder line-ups, and predive checkout procedures. In closed- and semi-closed-circuit UBA, breathing bags should be purged in accordance with Operating Procedures (OPs), and oxygen sensors should be monitored closely throughout the dive. Recently surfaced mixed-gas chambers should not be entered until after they are thoroughly ventilated with air.

3-5.1.3 Treatment of Hypoxia. A diver suffering from severe hypoxia must be rescued promptly. Hypoxia's interference with brain functions will produce not only unconsciousness but also failure of the breathing control centers. If a victim of hypoxia is given gas with adequate oxygen content before his breathing stops, he will usually regain consciousness shortly and recover completely. For SCUBA divers, this usually involves bringing the diver to the surface. For surface-supplied mixed-gas divers, it involves shifting the gas supply to alternative banks, and ventilating the helmet or chamber with the new gas. Details of treatment are covered in Chapter Eight, paragraph 8-2.1.

3-5.2 Excessive Carbon Dioxide (Hypercapnia). In diving operations, an excess of carbon dioxide in the blood (hypercapnia or hypercarbia) is generally the result of a buildup of carbon dioxide in the breathing supply or in the body as a result of:

- Inadequate ventilation of surface-supplied helmets
- Excess carbon dioxide in helmet supply gas (failure of CO_2 absorbent canister) in mixed-gas diving
- Failure of carbon dioxide absorbent canisters in closed- or semiclosed-circuit UBA
- Inadequate lung ventilation in relation to exercise level (caused by controlled breathing, excessive apparatus breathing resistance, increased oxygen partial pressure, or increased gas density).
- Any cause of increased dead space such as shallow and rapid breathing through a snorkel.

Current underwater breathing equipment is designed to keep the carbon dioxide below 1.5 percent during heavy work. The most common cause of hypercapnia is failure to ventilate helmets adequately. This usually occurs when the diver turns down the air control valve to enhance communications with the surface. On occasion, through improper breathing techniques or excessive breathing resistance, a diver can poison himself by inadequately ventilating his lungs. This happens primarily when a SCUBA diver tries to conserve his breathing supply by reducing his breathing rate below a safe level (skip-breathing). Inadequate lung ventilation is more common in diving than in surface activities for two reasons. First, some divers have a lower drive to increase lung ventilation in the face of increased blood CO_2 levels. Second, the usually high ppO_2 encountered in diving takes away some of the uncomfortable shortness of breath that accompanies inadequate lung ventilation. An excess of carbon dioxide (hypercapnia) affects the brain differently than does a lack of oxygen (hypoxia). However, it can result in similar symptoms such as confusion, inability to concentrate, drowsiness, loss of consciousness, and convulsions. Such effects become more severe as the degree of excess increases. A diver breathing a gas with as much as 10 percent carbon dioxide will generally lose consciousness after a few minutes. Breathing 15 percent carbon dioxide for any length of time will cause muscular spasms and rigidity.

A diver who loses consciousness because of excess carbon dioxide in his breathing medium, and does not aspirate water, generally revives rapidly when given fresh air. He will usually feel normal within 15 minutes, and the aftereffects rarely include symptoms more serious than headache, nausea, and dizziness. Permanent brain damage and death are much less likely than in the case of hypoxia.

The increasing level of carbon dioxide in the blood stimulates the respiratory center to increase the breathing rate and volume, and the heartbeat rate is often increased. Ordinarily, increased breathing is definite and uncomfortable enough to warn a diver before the $ppCO_2$ becomes very dangerous. However, variables such as work rate, depth, and the composition of the breathing mixture may produce changes in breathing and blood mixture that could mask any changes caused by excess carbon dioxide. This is especially true in closed-circuit UBA (especially 100-percent oxygen rebreathers) when failure or expenditure of the carbon dioxide absorbent material allows a carbon dioxide buildup while the amount of oxygen increases. In cases where the ppO_2 is above 0.5 ata, the shortness of breath usually associated with excess carbon dioxide may not be excessive and may go unnoticed by the diver, especially if he is breathing hard because of exertion. In these cases the diver may become confused and even slightly euphoric before losing consciousness. For this reason, a diver must be particularly alert for any marked change in his breathing comfort or cycle (such as shortness of breath or hyperventilation) as a warning of hypercapnia.

Excess carbon dioxide also dilates the arteries of the brain. This may partially explain the headaches often associated with carbon dioxide intoxication, though these headaches are more likely to occur following the exposure than during it. The increase in blood flow through the brain, which results from dilation of the arteries, is thought to explain why carbon dioxide excess speeds the onset of oxygen toxicity or possibly convulsions. Excess carbon dioxide toxicity during a dive is also believed to increase the likelihood of decompression sickness, but the reasons are less clear. Headache, cyanosis, unusual sweating, fatigue, and a general feeling of discomfort may warn a diver if they occur and are recognized, but they are not very reliable as warnings. Hypothermia also can mask the buildup of carbon dioxide because the respiration rate increases initially on exposure to cold water. Additionally, nitrogen narcosis can mask the condition because a diver under the effects of narcosis would not notice any difference in his breathing rate. During surface-supplied air dives deeper than 100 fsw (30.5 meters), the Diving Supervisor must ensure the divers maintain sufficient ventilation rates.

3-5.2.1 Treatment of Hypercapnia. Treatment of hypercapnia consists entirely of relieving the excess partial pressure of CO_2. This is accomplished in surface-supplied diving by ventilating the helmet with fresh air in an air diving apparatus, bypassing the carbon dioxide absorbent in a mixed-gas diving apparatus, or ascending. Any method used to decrease the partial pressure will remove the problems encountered with excess carbon dioxide. Details are found in Chapter Eight, paragraph 8-2.3.

3-5.3 Asphyxia. Asphyxia indicates the existence of both hypoxia and carbon dioxide excess in the body. Asphyxia occurs when breathing stops. Breathing stoppage can be due to injury or obstruction of air passages. It can be the result of an injury to the windpipe (trachea), the lodging of an inhaled object, the tongue falling back into the throat during unconsciousness, or the inhalation of water, saliva, or vomitus.

In many situations carbon dioxide excess or hypoxia occur separately, so specific terms should be used where possible. If hypoxia is severe or prolonged enough to stop a diver's breathing, carbon dioxide excess will develop rapidly and the condition will then be true asphyxia. At this point divers will no longer be able to breathe.

3-5.4 Breathing Resistance and Dyspnea. The ability to perform useful work underwater depends on the diver's ability to move enough gas in and out of his lungs to provide sufficient oxygen to the muscles and to eliminate metabolically produced carbon dioxide. There are two main factors which impede this ability: increased gas density and resistance of the breathing apparatus. Even in a dry hyperbaric chamber without a breathing apparatus, the increased gas density may cause divers to experience shortness of breath (dyspnea). If breathing air, this dyspnea usually becomes apparent at very heavy workloads at depths below 120 fsw. If breathing helium-oxygen, dyspnea usually becomes a problem at heavy workloads in the 850-1000 fsw range. At great depths (1600-1800 fsw), dyspnea may occur even at rest.

The breathing limitations imposed by the underwater breathing apparatus result from two main sources: flow resistance and static lung load. Flow resistance is due to a flow of dense gas through tubes, hoses, and orifices in the diving equipment. As gas density increases, a larger driving pressure must be applied to keep gas flowing at the same rate. The diver will have to exert higher negative pressures to inhale and higher positive pressures to exhale. As ventilation increases with increasing levels of exercise, the necessary driving pressures will increase. Because the respiratory muscles can only exert so much effort to inhale and exhale, a point will be reached when further increases will not occur. At this point, metabolically produced carbon dioxide will not be adequately eliminated and will increase in the blood causing symptoms of hypercapnia.

Static lung load is the result of breathing gas being supplied at a different pressure than the hydrostatic pressure surrounding the lungs. For example, when swimming horizontally with a single-hose regulator, the regulator diaphragm is lower than the mouth and the regulator will supply gas at a slight positive pressure once the demand valve has opened. If the diver flips onto his back, the regulator diaphragm will be shallower than his mouth and the regulator will supply gas at a slightly negative pressure. Inhalation will be harder but exhalation will be easier because the exhaust ports are above the mouth and at a slightly lower pressure.

Static lung loading is more apparent in closed-circuit underwater breathing apparatus such as the MK 15 and MK 16. When swimming horizontally, the diaphragm on the diver's back is shallower than the lungs and the diver feels a negative pressure at the mouth. Exhalation is easier than inhalation. If the diver flips onto his back, the diaphragm is below the lungs and the diver feels a positive pressure. Inhalation becomes easier than exhalation. At high work rates, excessively high or low static lung loads may cause dyspnea without any increase in blood carbon dioxide level.

The U.S. Navy makes every effort to ensure that UBA meet adequate breathing standards so that flow resistance and static lung loading problems are minimized. However, all UBA have their limitations and divers must have sufficient experience to recognize those limitations. If the UBA does not impede ventilation, the diver's own pulmonary system may limit his ability to ventilate. Whether due to limitations of the equipment or limitations imposed by the diver's own respiratory system, the end result may be symptoms of hypercapnia or dyspnea without increased carbon dioxide blood levels. This is commonly referred to as "overbreathing the rig". Most divers will decrease their level of exertion when they begin to experience dyspnea, but in some cases, depending on the depth and type of UBA, the dyspnea may continue to increase for a period of time after stopping exercise. When this occurs, the inexperienced diver may panic and begin to hyperventilate (breathe faster than is necessary for the exchange of respiratory gases) which increases the dyspnea. The situation rapidly develops into one of severe dyspnea and uncontrollable hyperventilation. In this situation, if even a small amount of water is inhaled, it can cause a spasm of the muscles in the larynx (voice box) called a laryngospasm, followed by asphyxia and possible drowning. The proper reaction to the dyspnea is to stop exercising, ventilate the UBA if possible, take even, controlled breaths until the dyspnea subsides, evaluate the situation, and then proceed carefully. Generally, soreness of the respiratory muscles is the only prominent aftereffect of a dive in which breathing resistance is high.

3-5.5 Carbon Monoxide Poisoning. Carbon monoxide in a diver's air supply is dangerous. It is not found in any significant quantity in fresh air. Carbon monoxide pollution of a breathing supply is usually caused by the exhaust of an internal combustion engine close to a compressor intake. Concentrations as low as 0.002 ata can prove fatal. Carbon monoxide is harmful because it displaces oxygen from hemoglobin and interferes with cellular metabolism; in effect, it renders cells hypoxic.

The symptoms of carbon monoxide poisoning are almost identical to those of other types of hypoxia. The greatest danger is that unconsciousness can occur without reliable warning signs. When the concentration of carbon monoxide is high enough to cause rapid onset of poisoning, the victim may not be aware of weakness, dizziness, or confusion before he becomes unconscious. When toxicity develops gradually, symptoms like tightness across the forehead, headache and pounding at the temples, or nausea and vomiting may be warnings.

A particularly treacherous factor in carbon monoxide poisoning is that conspicuous symptoms may be delayed until the diver begins to ascend. While at depth, the greater partial pressure of oxygen in the breathing supply will force more oxygen into solution in the blood plasma. Some of this additional oxygen reaches the cells and helps to offset the hypoxia. In addition, the increased partial pressure of oxygen forcibly displaces some carbon monoxide from the hemoglobin. During ascent, as the partial pressure of oxygen diminishes, the full effect of carbon monoxide poisoning will be felt.

The immediate treatment of carbon monoxide poisoning consists of getting the diver to fresh air and seeking medical attention. If oxygen is available, it should be administered immediately and while transporting the patient to a hyperbaric or medical treatment facility. Hyperbaric oxygen therapy is the definitive treatment of choice and transportation for recompression should not be delayed except to stabilize the serious patient prior to transport. The air supply of a diver suspected of suffering carbon monoxide poisoning must be secured to prevent anyone else from breathing it, and the air must be analyzed.

Carbon monoxide poisoning can be prevented. Compressor intakes must be located away from engine exhausts and air compressors must be maintained in the best possible mechanical condition.

3-5.6 Breathholding and Unconsciousness. Most people can hold their breath approximately one minute, but usually not much longer without training or special preparation. At some time during a breathholding attempt, the desire to breathe will become uncontrollable. This demand is signalled by the respiratory center responding to the increasing levels of carbon dioxide and acids in the arterial blood, and chemoreceptors responding to the corresponding fall in the level of oxygen and the rise in arterial carbon dioxide.

In the U.S. Navy, breathhold diving shall be confined to specific training situations such as the pool phase of SCUBA training and free ascent training. The length of time that a diver can hold his breath can be dramatically increased by two methods: hyperventilation and breathing pure oxygen just before a dive.

Hyperventilation means breathing more than necessary to eliminate the carbon dioxide produced by metabolism. By overventilating the lungs, the diver reduces the partial pressure of carbon dioxide in the blood below a normal level, and can therefore hold his breath longer while the carbon dioxide level is building up to the point at which the respiratory center will force resumption of breathing. The practice of hyperventilation shall not be conducted except where necessary in specific training. The carbon dioxide level that provides the stimulus to breathe and causes the diver to feel air hunger before hypoxia occurs and causes unconsciousness.

If the carbon dioxide stores are ventilated below the stimulus level, there will be little urge to breathe until late in the breathhold. The oxygen partial pressure will progressively fall as oxygen is consumed continuously. Low levels of oxygen do not cause a powerful demand to resume breathing; thus, the level of oxygen in the blood may reach the point at which the diver will lose consciousness before he feels a demand to breathe.

One of the greatest hazards of breathhold diving is the possible loss of consciousness during ascent. Air in the lungs during descent is compressed, raising the oxygen partial pressure. The increased ppO_2 readily satisfies the body's oxygen demand during descent and while on the bottom, even though a portion is being consumed by the body. During ascent, the partial pressure of the remaining oxygen is reduced rapidly as the hydrostatic pressure on the body lessens. If the ppO_2 falls below 11 percent (83.6 mmHg), unconsciousness may result with its attendant danger. This danger is further heightened when hyperventilation has eliminated normal body warning signs of CO_2 accumulation.

3-5.7 Hyperventilation. Hyperventilation is the term applied to breathing more than is necessary to keep the body's carbon dioxide tensions at proper level. Hyperventilation has little effect on the body's oxygen levels, but it can reduce carbon dioxide partial pressure to the point of producing serious symptoms. Extreme hyperventilation is undesirable and can be dangerous.

Unintentional hyperventilation is most often triggered by fear experienced during stressful situations. It can be partly initiated by the slight "smothering sensation" that accompanies an increase in dead space, abnormal static loading, and increased breathing resistance. Cold water exposure can add to the sensation of needing to breathe faster and deeper. Divers using SCUBA equipment for the first few times are likely to hyperventilate to some extent because of anxiety.

Voluntary hyperventilation (taking a number of deep breaths over a short period of time) can produce symptoms of abnormally low carbon dioxide tension (hypocapnia). Under these circumstances, one rarely develops more than lightheadedness and tingling sensations. When hyperventilating over a long period, however, additional symptoms such as weakness, headaches, numbness, faintness, and blurring of vision may appear. The anxiety caused by the sensation of suffocation that often initiates hyperventilation, and continues in spite of adequate ventilation, may lead to a further increase in breathing, and a vicious cycle develops. Severe hypocapnia with muscular spasms, loss of consciousness, and shock may be the end result. Severe cases are extremely rare in diving, but the possibility deserves attention. Milder instances are more common. The diver must pay attention to his breathing rate, and in the event of fear-induced hyperventilation, take steps to remain calm and control his breathing.

3-6 BAROTRAUMA AND MECHANICAL EFFECTS OF PRESSURE

The tissues of the body can withstand tremendous pressure. Divers have made open-sea dives in excess of 1000 fsw (445 psi) and, in experimental situtations, have been exposed to a depth of 2250 fsw (1001.3 psi). Despite these pressures, it is somewhat ironic that divers make the greatest number of medical complaints during the shallowest part of a dive. The cause is barotrauma, which is the damage done to tissues when there is a change in ambient pressure. Barotrauma of descent is called squeeze. Barotrauma of ascent is called reverse squeeze.

There are five conditions that must be present for barotrauma to occur.

(1) There must be a gas-filled space. Most of the body is fluid and not compressible. However, any gas-filled space naturally present within the body (sinus) or next to the body (face mask) can damage the body tissues when the gas volume changes as described by Boyle's Law.

(2) The space must have rigid walls. When the walls are elastic like a balloon, there will be no damage done by gas compression or expansion until the volume change surpasses the elasticity of the walls or vessels.

(3) The space must be enclosed. If any substance (with the exception of blood in the vessels lining the space) were allowed to enter or leave the space as the gas volume changes, no damage would occur.

(4) The space must have vascular penetration (arteries and veins) and a membrane lining the space. This allows the blood to be forced into the space and exceed the elasticity of the vessels to compensate for the change in pressure.

(5) There must be a change in ambient pressure.

It is important to note that barotrauma will not normally occur in divers who have normal anatomy and physiology, and who are using properly functioning equipment and correct diving procedures.

The predominant symptom of barotrauma is pain. Other symptoms such as vertigo, numbness, or facial paralysis may be produced depending on the specific anatomy. Pulmonary Overinflation Syndrome is a potentially serious form of barotrauma and is discussed in detail later in this chapter. In all diving situations, arterial gas embolism and decompression sickness must be ruled out before the diagnosis of squeeze can be accepted.

In the remainder of this section, specific types of barotrauma and their related conditions are discussed.

3-6.1 Middle Ear Squeeze. Middle ear squeeze is the most common type of barotrauma. The anatomy of the ear is illustrated in Figure 3-7. The eardrum completely seals off the outer ear canal from the middle ear space. As a diver descends, water pressure on the external surface of the drum increases. To counterbalance this pressure, the air pressure must reach the inner surface of the eardrum. This is accomplished by the passage of air through the narrow eustachian tube which leads from the nasal passages to the middle ear space.

When the eustachian tube is blocked by mucous, the middle ear meets four of the requirements for barotrauma to occur (gas filled space, rigid walls, enclosed space, penetrating blood vessels).

As the diver continues his descent, the fifth requirement (change in ambient pressure) is attained. As the pressure increases, the eardrum will bow inward and initially equalize the pressure by compressing the middle ear gas. There is a limit to this stretching capability and soon the middle ear pressure becomes lower than the external water pressure, creating a relative vacuum in the middle ear space. This negative pressure causes the blood vessels of the eardrum and lining of the middle ear to first expand, then leak, and finally burst. If descent continues, either the eardrum will rupture, allowing air or water to enter the middle ear and equalize the pressure, or blood vessels will rupture and cause sufficient bleeding into the middle ear to equalize the pressure. The latter usually happens.

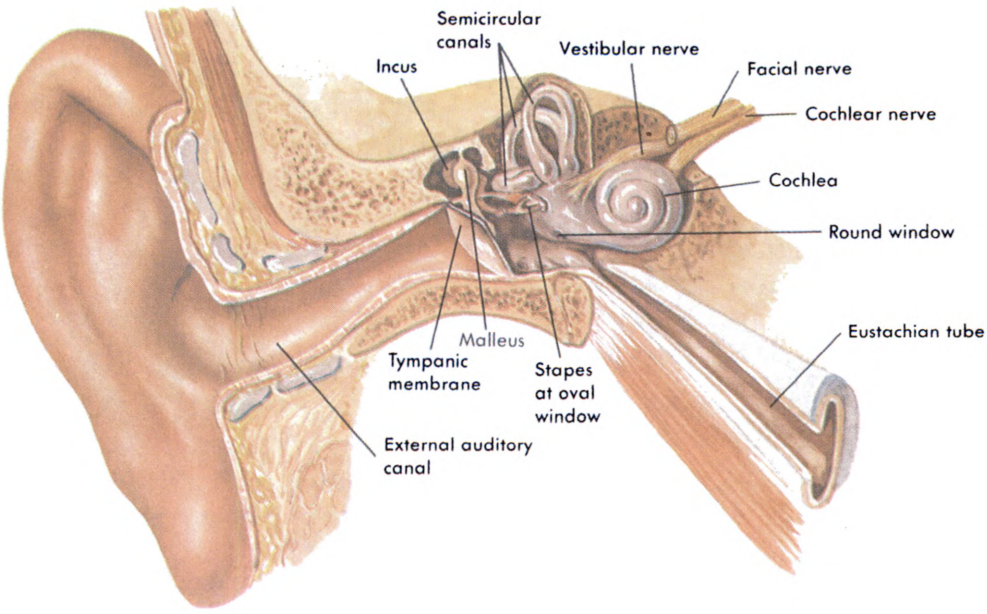


Figure 3-7. Gross Anatomy of the Ear in Frontal Section.

The hallmark of middle ear squeeze is sharp pain caused by stretching of the eardrum. The pain produced before rupture of the eardrum often becomes intense enough to prevent further descent. Simply stopping the descent and ascending a few feet usually brings about immediate relief.

If descent continues in spite of the pain, the eardrum may rupture. Unless the diver is in hard hat diving dress, the middle ear cavity may be exposed to water when the eardrum ruptures. This exposes the diver to a possible middle ear infection and, in any case, will prevent the diver from diving until the damage is healed. At the time of the rupture, the diver may experience the sudden onset of a brief but violent episode of vertigo (a sensation of spinning). This can completely disorient the diver and cause nausea and vomiting. This vertigo is caused by violent disturbance of the maleus, incus, and stapes, or by cold water stimulating the balance mechanism of the inner ear. The latter situation is referred to as caloric vertigo and may occur from simply having cold or warm water enter one ear and not the other. The eardrum does not have to rupture for caloric vertigo to occur. It can occur as the result of having water enter one ear canal when swimming or diving in cold water. Fortunately, these symptoms will quickly pass when the water reaching the middle ear is warmed by the body.

The best method of handling middle ear squeeze is to avoid it. Remember that the possibility of barotrauma can be virtually eliminated if certain precautions are taken. While descending, stay ahead of the pressure. To avoid collapse of the eustachian tube and to clear the ears, frequent adjustments of middle ear pressure must be made by adding gas through the eustachian tubes from the back of the nose. If too large a pressure difference develops between the middle ear pressure and the external pressure, the eustachian tube will collapse as it becomes swollen and blocked. For some divers, the eustachian tube is open all the time so no conscious effort is necessary to clear their ears. For the majority, however, the eustachian tube is normally closed and some action must be taken to clear the ears. Many divers can do this by yawning, swallowing, or moving the jaw around. Some divers must gently force gas up the eustachian tube by closing their mouth, pinching their nose, and exhaling. This is called a Valsalva maneuver. If too large a relative vacuum exists in the middle ear, the eustachian tube will collapse and no amount of forceful clearing will open it. If a squeeze is noticed during descent, the diver shall stop, ascend a few feet, and gently perform a Valsalva maneuver. NEVER DO A FORCEFUL VALSALVA DURING DESCENT! This could result in alternobaric vertigo or a round or oval window rupture (discussed later in this chapter). Also, NEVER DO A FORCEFUL VALSALVA DURING ASCENT! This could result in a pulmonary overinflation syndrome (also discussed later in this chapter). If clearing cannot be accomplished as described above, abort the dive.

Upon surfacing after a middle ear squeeze, the diver may complain of pain, fullness in the ear, hearing loss, or even mild vertigo. Occasionally, blood may be in the nostrils as the result of blood being forced through the eustachian tube by expanding air in the middle ear. The diver shall report this to the diving supervisor and seek medical attention. Treatment consists of taking decongestants and cessation of diving until the damage is healed.

Diving with a partially blocked eustachian tube increases the likelihood of middle ear squeeze. Divers who cannot clear their ears on the surface should not dive. Divers who have trouble clearing shall be examined by medical personnel before diving.

3-6.2 Sinus Squeeze. Sinuses are located within hollow spaces of the skull bones and are lined with a mucous membrane continuous with that of the nasal cavity (Figure 3-8). The sinuses are small air pockets connected to the nasal cavity by narrow passages. If pressure is applied

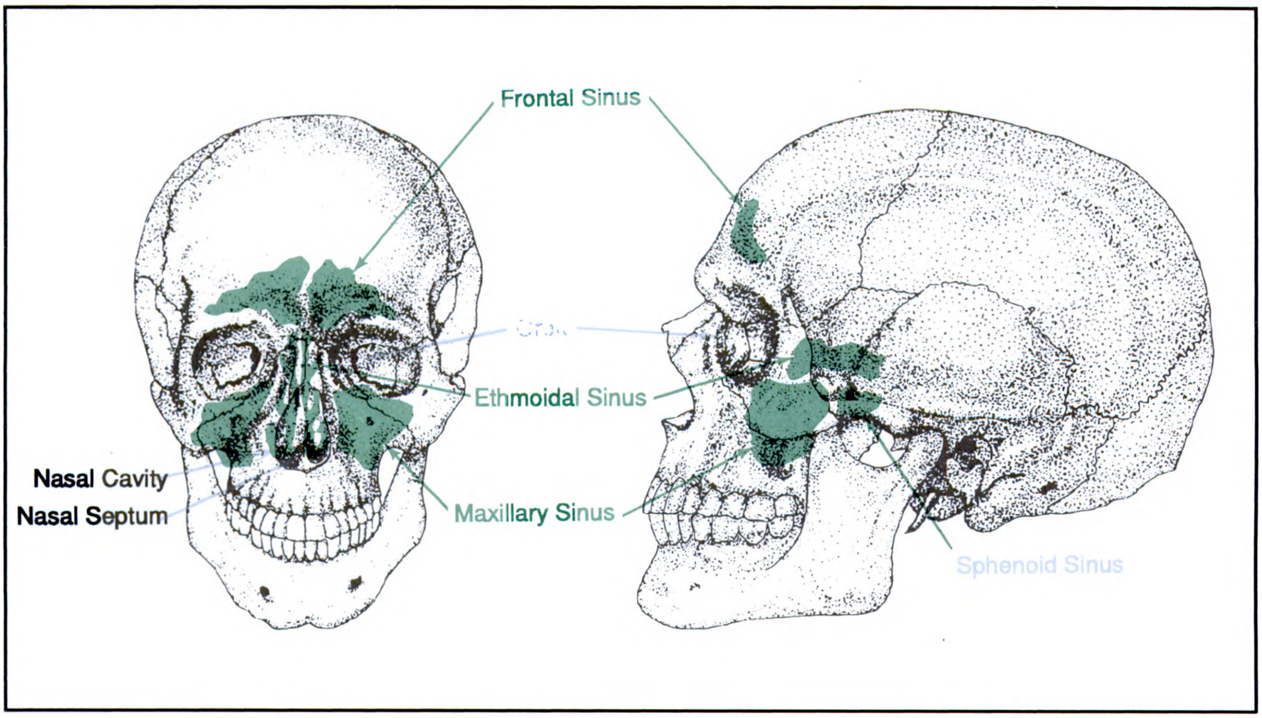


Figure 3-8. Location of the Sinuses in the Human Skull.

to the body and the passages to any of these sinuses are blocked by mucous or tissue growths, pain will soon be experienced in the affected area. The situation will be very much like that described for the middle ear. When the air pressure in these sinuses is less than the pressure applied to the tissues surrounding these incompressible spaces, the same relative effect is produced as if a vacuum were created within the sinuses: the lining membranes will swell, and, if severe enough, hemorrhage into the sinus spaces. This process represents nature's effort to balance the relative negative air pressure by filling the space with swollen tissue, fluid, and blood. The sinus is actually squeezed. The pain produced may be intense enough to halt the diver's descent. Unless damage has already occurred, a return to normal pressure will bring about immediate relief, as in the case of pain in the middle ear. If such difficulty has been encountered during a dive, the diver may often notice a small amount of bloody nasal discharge on reaching the surface.

The best method of handling sinus squeeze, like a middle ear squeeze, is to avoid it. Divers should not dive if any signs of nasal congestion or a head cold are evident. The effects of squeeze can be limited during a dive by halting the descent and ascending a few feet to restore the pressure balance. If the space cannot be equalized (by swallowing or blowing against a pinched-off nose), the dive must be aborted.

3-6.3 Tooth Squeeze (Barodontalgia). Tooth squeeze occurs when a small pocket of gas, generated by decay, is lodged under a poorly-fitted or cracked filling. If this pocket of gas is completely isolated, the pulp of the tooth or the tissues in the tooth socket can be sucked into the space causing pain. If additional gas enters the tooth during descent and does not vent during ascent, it can cause the tooth to crack or the filling to be dislodged. Prior to any dental work, personnel shall identify themselves as divers to the dentist.

3-6.4 External Ear Squeeze. A diver who wears ear plugs, has an infected external ear (external otitis), has a wax-impacted ear canal, or wears a tight-fitting wet suit hood, can develop an external ear squeeze. The squeeze occurs when gas trapped in the external ear canal remains at atmospheric pressure while the external water pressure increases during descent. In this case, the eardrum bows outward (opposite of middle ear squeeze) in an attempt to equalize the pressure difference and may rupture. The skin of the canal swells and hemorrhages, causing considerable pain.

The best method of handling external ear squeeze is to avoid it. Ear plugs must never be worn while diving. In addition to creating the squeeze, they may be forced deep into the ear canal. When a hooded suit must be worn, air (or water in some types) must be allowed to enter the hood to equalize pressure in the ear canal.

3-6.5 Thoracic (Lung) Squeeze. When making a breathhold dive, it is possible to reach a depth at which the air held in the lungs will be compressed to a volume somewhat smaller than the normal residual volume of the lungs. At this volume, the chest wall becomes stiff and incompressible. If the diver descends further, the additional pressure will be unable to compress the chest walls, force additional blood into the blood vessels in the chest, or elevate the diaphragm further, and the pressure in the lung will become negative with respect to the external water pressure. Injury will take the form of squeeze. Blood and tissue fluids will be forced into the lung alveoli and air passages where the air is under less pressure than the blood in the surrounding vessels. This amounts to an attempt to relieve the negative pressure within the lungs by partially filling the air space with swollen tissue, fluid and blood. Considerable lung damage results and, if severe enough, may prove fatal. If the diver descends still further, death will occur as a result of the collapse of the chest. Breathhold diving shall be limited to controlled, training situations or special operational situations involving well-trained personnel at shallow depths.

A surface-supplied diver who suffers a loss of gas pressure or hose rupture with failure of the nonreturn valve may suffer a lung squeeze, if his depth is great enough, as the surrounding water pressure compresses his chest. The best method to handle a lung squeeze is to avoid it.

3-6.6 Face or Body Squeeze. SCUBA face masks, goggles, and certain types of exposure suits may cause squeeze under some conditions. The pressure in a face mask can usually be equalized by exhaling through the nose, but this is not possible with goggles. Goggles shall only be used for surface swimming. The eye and the eye socket tissues are the most seriously affected tissues in an instance of face mask or goggle squeeze. When using exposure suits, air may be trapped in a fold in the garment and may lead to some discomfort and possibly a minor case of hemorrhage into the skin from pinching.

3-6.7 Middle Ear Overpressure (Reverse Middle Ear Squeeze). Expanding gas in the middle ear space during ascent ordinarily vents out through the eustachian tube. If the tube becomes blocked, pressure in the middle ear relative to the external water pressure increases. To relieve this pressure, the eardrum bows outward causing pain. If the overpressure is significant, the eardrum may rupture and the diver may experience the same symptoms that occur with an eardrum rupture during descent (squeeze).

The increased pressure in the middle ear may also affect nearby structures and produce symptoms of vertigo and inner ear damage. It is extremely important to rule out arterial gas embolism or decompression sickness when these unusual symptoms of reverse middle ear squeeze occur during ascent or upon surfacing.

The best method to handle reverse middle ear overpressurization is to avoid it. Divers who have a cold or are unable to equalize the ears will more likely develop reverse middle ear squeeze. There is no uniformly effective way to clear the ears on ascent. Do not valsalva on ascent as this will increase the pressure in the middle ear, which is the direct opposite of what is required. The Valsalva maneuver can also lead to the possibility of an arterial gas embolism. If pain in the ear develops on ascent, the diver should halt the ascent, descend a few feet to relieve the symptoms and then continue his ascent at a slower rate. Several such attempts may be necessary as the diver gradually works his way to the surface.

3-6.8 Sinus Overpressure (Reverse Sinus Squeeze). Overpressure is caused when gas is trapped within the sinus cavity. A fold in the sinus-lining membrane, a cyst, or an outgrowth of the sinus membrane (polyp) may act as a check valve and prevent gas from leaving the sinus during ascent. Sharp pain in the area of the affected sinus results from the increased pressure. The pain will usually be sufficient to stop the diver from ascending. Pain is immediately relieved by descending a few feet. From that point, the diver should slowly ascend until he gradually reaches the surface.

3-6.9 Overexpansion of the Stomach and Intestine. While a diver is under pressure, gas may form within his intestines, or gas may be swallowed and trapped in the stomach. On ascent, this trapped gas expands and occasionally causes enough discomfort to require the diver to stop and expel the gas. Continuing ascent in spite of marked discomfort may result in actual harm.

3-6.10 Inner Ear Dysfunction and Vertigo. The inner ear contains no gas and is not subject to barotrauma. However, the inner ear is located next to the middle ear cavity and is affected by the same conditions that produce middle ear barotrauma. As the gas in the middle ear is compressed or expands without the relief normally provided by the eustachian tube, the fluid and membranes of the delicate inner ear will be functionally disturbed. The membranes may tear as the pressure gradient increases.

The inner ear contains two important organs, the cochlea and the vestibular apparatus. The cochlea is the hearing sense organ; damage to the cochlea can result in symptoms of hearing loss and ringing in the ear (tinnitus). The vestibular apparatus senses balance and motion; damage to the vestibular apparatus may cause vertigo, which is the false sensation of a spinning type of motion. The diver will feel that he or the surrounding area is spinning while in fact there is no motion. One can usually tell this distinct sensation from the more vague complaints of dizziness or lightheadedness caused by other conditions. Vertigo is usually specific to the inner ear or that part of the brain which analyzes inner ear input. Vertigo has associated symptoms which may or may not be noticed. These include nausea, vomiting, loss of balance, incoordination, and a rapid jerking movement of the eyes (nystagmus). Vertigo may also be caused by arterial gas embolism or Type II decompression sickness, which are described in Chapter Eight.

Frequent oscillations in middle ear pressure associated with difficult clearing may lead to a condition of transient vertigo called alternobaric vertigo of descent. This vertigo usually follows a Valsalva maneuver, often with the final clearing episode just as the diver reaches the bottom. The vertigo is short-lived but may cause significant disorientation.

Alternobaric vertigo may also occur during ascent in association with middle ear overpressurization. In this case, the vertigo is often preceded by a feeling of fullness or pain in the ear that is not venting excess pressure. The vertigo usually lasts for only a few minutes, but may be incapacitating during that time. Relief is abrupt and may be accompanied by a hissing sound in the affected ear. Alternobaric vertigo during ascent will disappear immediately if the diver halts his ascent and descends a few feet.

A pressure imbalance between the middle ear and external environment may cause lasting damage to the inner ear if the imbalance is sudden or large. This type of inner ear barotrauma is often associated with rupture of the round or oval window.

There are three bones in the middle ear: the malleus, the incus, and the stapes. They are commonly referred to as the hammer, anvil, and stirrup, respectively (Figure 3-9). The malleus is connected to the eardrum (tympanic membrane) and transmits sound vibrations to the incus, which in turn transmits these vibrations to the stapes, which relays them to the inner ear. The stapes transmits these vibrations to the inner ear fluid through a membrane-covered hole called the oval window. Another membrane-covered hole called the round window connects the inner ear with the middle ear and relieves pressure waves in the inner ear caused by movement of the stapes.

Barotrauma can cause rupture of the round window membrane with associated leakage of the inner ear fluid (perilymphatic fluid). A persistent opening following barotrauma that drains perilymphatic fluid from the inner ear into the middle ear is referred to as a perilymph fistula. This condition can occur when the diver exerts himself, causing an increase in intracranial pressure. If great enough, this pressure can be transmitted to the inner ear causing severe damage to the round window membrane. The oval window is very rarely affected by barotrauma because it is protected by the foot of the stapes. Inner ear damage can also result from overpressurization of the middle ear by a too forceful Valsalva maneuver. The maneuver, in addition to its desired effect of forcing gas up the eustachian tube, increases the pressure of fluid within the

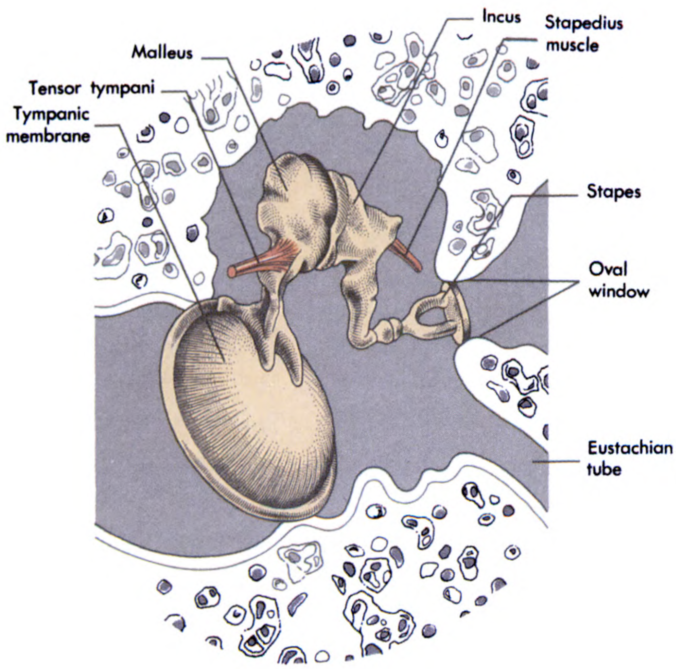


Figure 3-9. Impedence Matching Components of Inner Ear.

inner ear. Symptoms of this inner ear dysfunction include ringing or roaring in the affected ear, vertigo, disorientation, nystagmus, unsteadiness, and marked hearing loss. The diagnosis of inner ear barotrauma should be considered whenever any inner ear symptoms occur during compression or after a shallow dive in which decompression sickness is unlikely. In some cases it will be difficult to distinguish between symptoms of inner ear barotrauma and decompression sickness or arterial gas embolism. Recompression will not be harmful if it turns out barotrauma was the cause of the symptoms, provided the simple precautions outlined in Chapter Eight are followed. When in doubt, recompress. All cases of suspected inner ear barotrauma should be referred to an ear, nose, and throat (ENT) physician as soon as possible. Treatment of inner ear barotrauma ranges from bed rest to exploratory surgery, depending on the severity of the symptoms.

3-7 PULMONARY OVERINFLATION SYNDROMES

Pulmonary overinflation syndromes are a group of barotrauma-related diseases caused by the expansion of gas trapped in the lung during ascent (reverse squeeze) or overpressurization of the lung with subsequent overexpansion and rupture of the alveolar air sacs. The two main causes of alveolar rupture are:

(1) excessive pressure inside the lung caused by positive pressure, and

(2) failure of expanding gas to escape from the lung during ascent.

Excess pressure inside the lung can also occur when a diver presses the purge button on a single-hose regulator while taking a breath.

Pulmonary overinflation from expanding gas failing to escape from the lung during ascent can occur when a diver voluntarily or involuntarily breathholds during ascent. Localized pulmonary obstructions that can cause air trapping, such as asthma, thick secretions from pneumonia, or a severe cold, are other causes. The conditions that bring about these incidents are different from those that produce lung squeeze, and they most frequently occur during free and buoyant ascent training or emergency ascent from dives made with lightweight diving equipment or SCUBA.

The clinical manifestations of pulmonary overinflation depend on the location at which the free air collects. In all cases, the first step is rupture of the alveolus with a collection of air in the lung tissues, a condition known as interstitial emphysema. Interstitial emphysema causes no symptoms unless further distribution of the air occurs. Gas may find its way into the chest cavity or arterial circulation. These various conditions are depicted in Figure 3-10.

3-7.1 Arterial Gas Embolism. Arterial gas embolism is the most serious potential complication of diving and is caused by an excess pressure inside the lungs that fails to vent during ascent (Figure 3-11). For example, if a diver ascends to the surface from a depth of 100 feet, the air within his lungs will expand to four times its original volume. If this expanding air is not allowed to escape, pressure builds up within the lungs, overexpanding them and rupturing their air sacs and blood vessels. Air is then forced into the pulmonary capillary bed, and bubbles are carried to the left chambers of the heart, where they are then pumped out into the arteries. Any bubble that is too large to go through an artery will lodge and form a plug (embolus). The tissues beyond the plug will then be deprived of their blood supply and their oxygen. 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

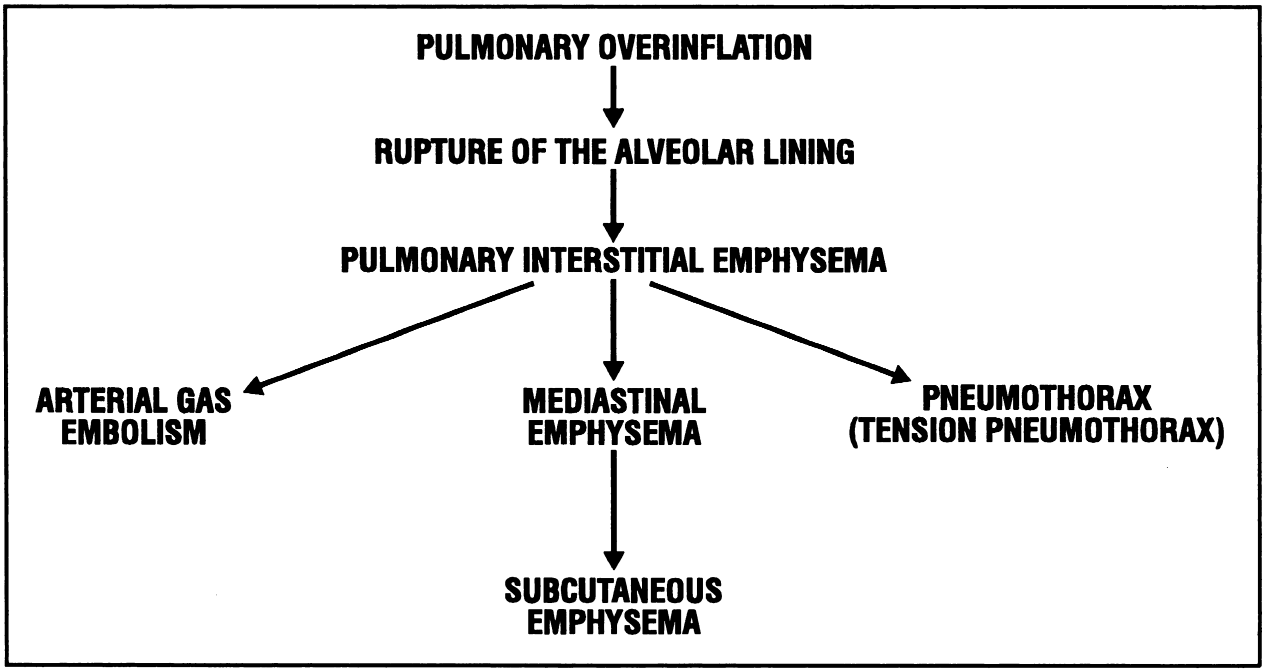


Figure 3-10. Pulmonary Overinflation Consequences. Leaking of gas into the pulmonary interstitial tissue causes no symptoms unless further leaking occurs. If gas enters the arterial circulation, potentially fatal arterial gas embolism may occur. Pneumothorax occurs if gas accumulates between the lung and chest wall and if accumulation continues without venting, then tension pneumothorax may result.

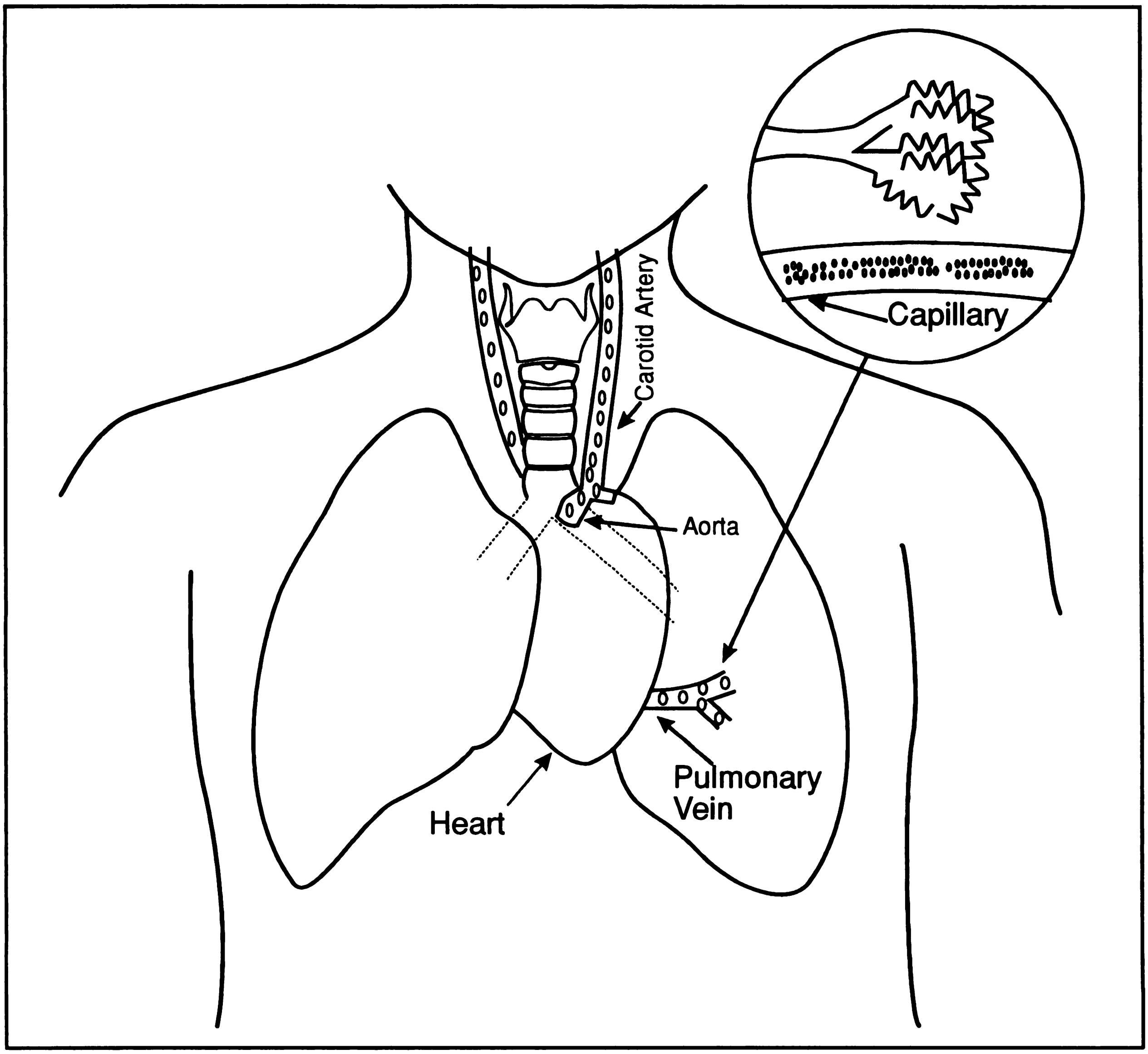


Figure 3-11. Arterial Gas Embolism

bubble and permit blood to flow again, death may follow. The symptoms and treatment of arterial gas embolism are discussed more fully in Chapter Eight.

A diver shall never hold his breath on ascent. A diver who does may feel a sensation of discomfort behind the breast bone (sternum) and a stretching of the lungs. Inhalation of water and fear can also trigger a spasm of the laryngeal muscles (laryngospasm) that seals the main lung passageway, and thus brings about the overexpansion of the lungs. Under these circumstances, death has occurred during ascent from depths of only a few feet. Every diver shall make it an absolute rule to breathe normally and continually during ascent. However, a diver who cannot breathe because he is out of air or because his gear is not working must exhale during ascent.

3-7.2 Mediastinal and Subcutaneous Emphysema. Mediastinal emphysema (Figure 3-12) occurs when gas has been forced through torn

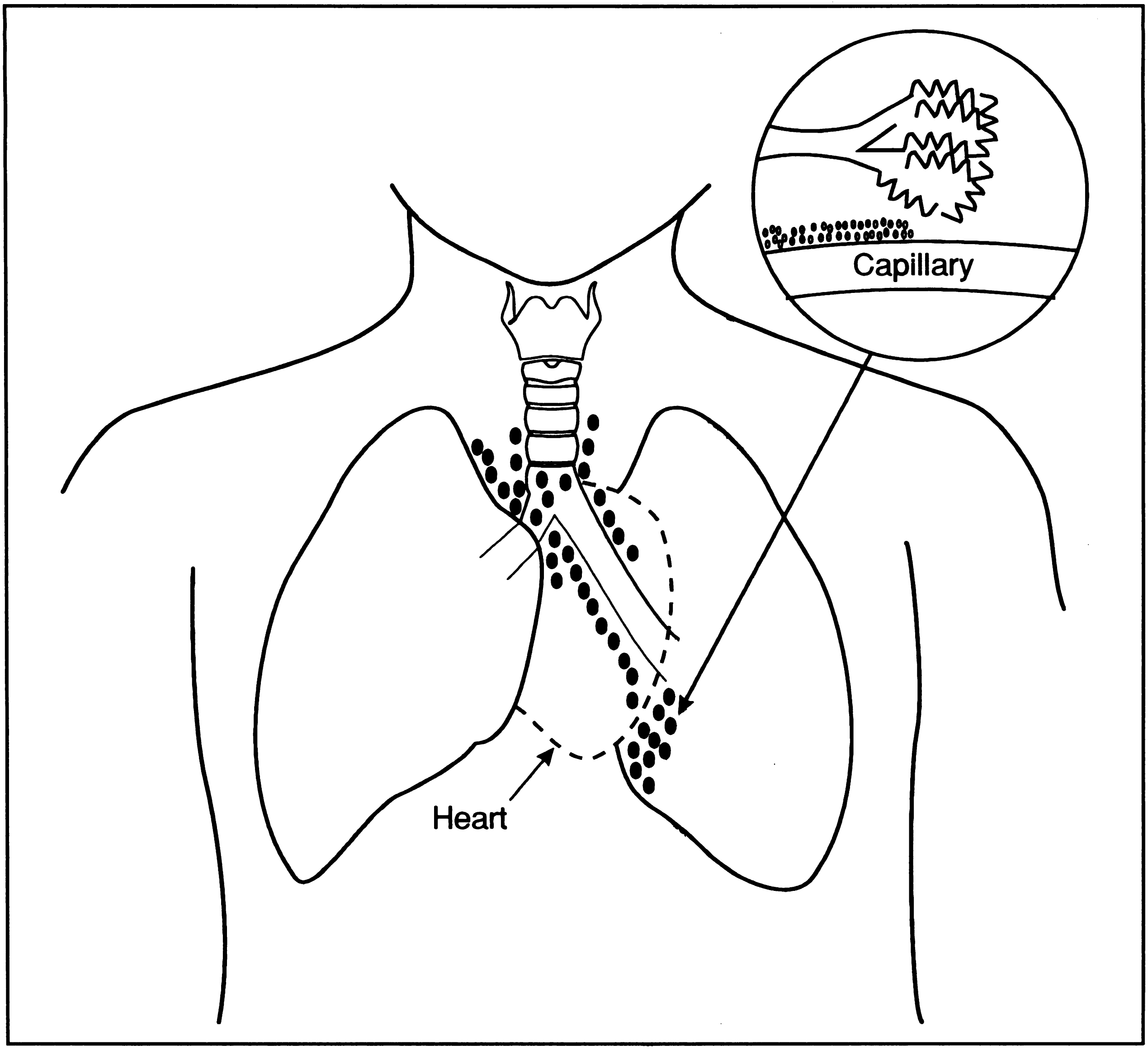


Figure 3-12. Mediastinal Emphysema.

lung tissue into the loose mediastinal tissues in the middle of the chest, around the heart, the trachea, and the major blood vessels. Subcutaneous emphysema (Figure 3-13) results from the expansion of gas that has leaked from the mediastinum into the subcutaneous tissues of the neck. These types of emphysema, including interstitial emphysema, should not be confused with the emphysema brought on by the aging process or by smoking.

3-7.3 Pneumothorax. Pneumothorax is the result of air entering the potential space between the lung covering and the lining of the chest wall (Figure 3-14). In its usual manifestation, called a simple pneumothorax, a one-time leakage of air from the lung into the chest partially collapses the lung, causing varying degrees of respiratory distress. This condition normally improves with time as the air is reabsorbed. In severe cases of collapse, the air must be removed with the aid of a tube or catheter. The onset of pneumothorax is accompanied by a sudden, sharp chest pain, followed by difficult,

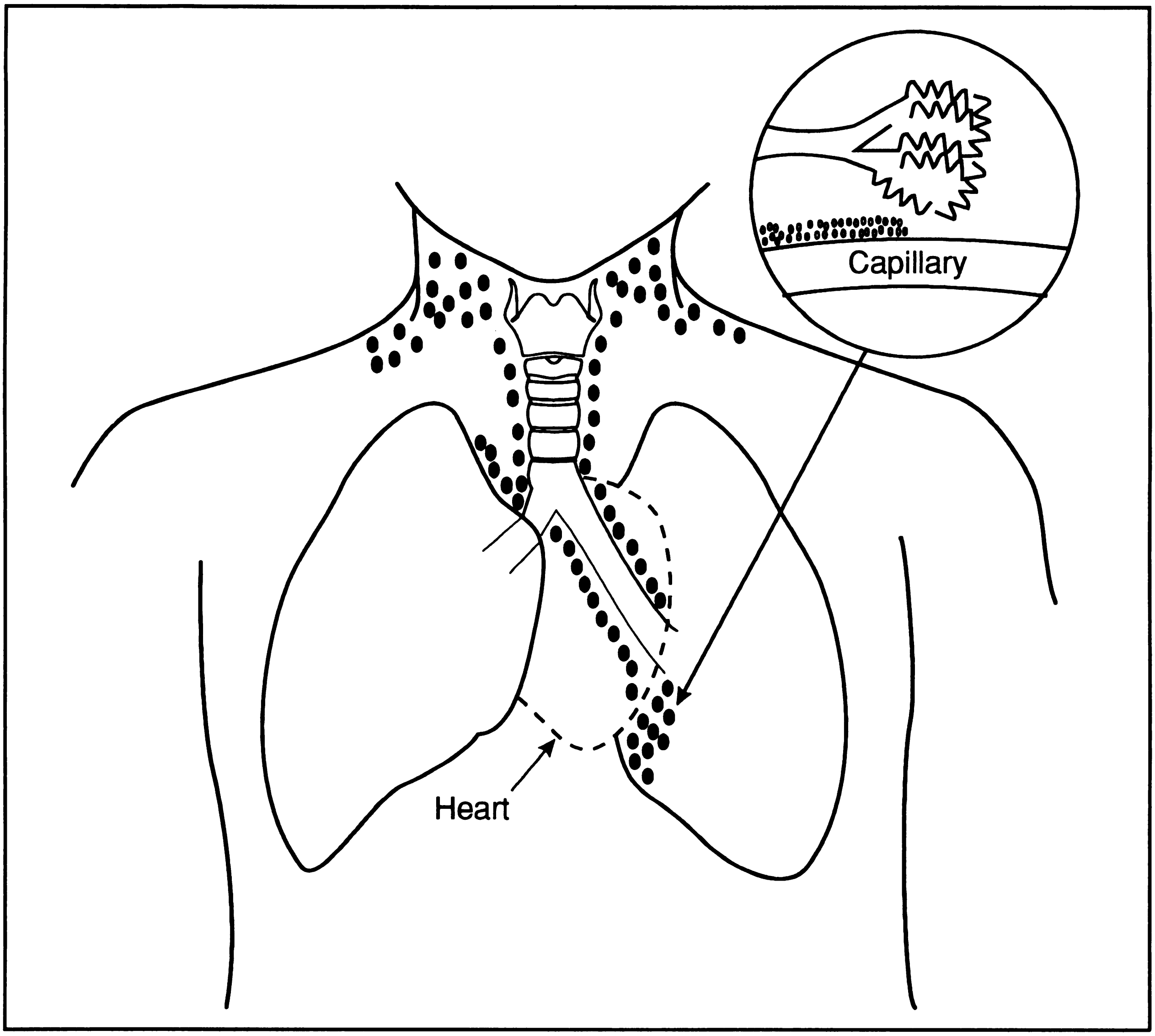


Figure 3-13. Subcutaneous Emphysema.

rapid breathing, cessation of normal chest movements on the affected side, tachycardia, a weak pulse and anxiety. A diver believed to be suffering from pneumothorax shall be thoroughly examined for the presence of arterial gas embolism. This is covered more fully in Chapter Eight.

In certain instances, the damaged lung may allow air to enter but not exit the pleural space. Successive breathing gradually enlarge the air pocket. This is called a tension pneumothorax (Figure 3-15) due to the progressively increasing tension or pressure exerted on the lung and heart by the expanding gas. If uncorrected, this force will press on the involved lung, causing it to completely collapse. The lung, and then the heart, are pushed toward the opposite side of the chest which compromises both respiration and circulation. The symptoms become progressively more serious, beginning with rapid breathing and ending in cyanosis, hypotension (low blood pressure), shock, and, unless corrected, death.

If a simple pneumothorax occurs in a diver

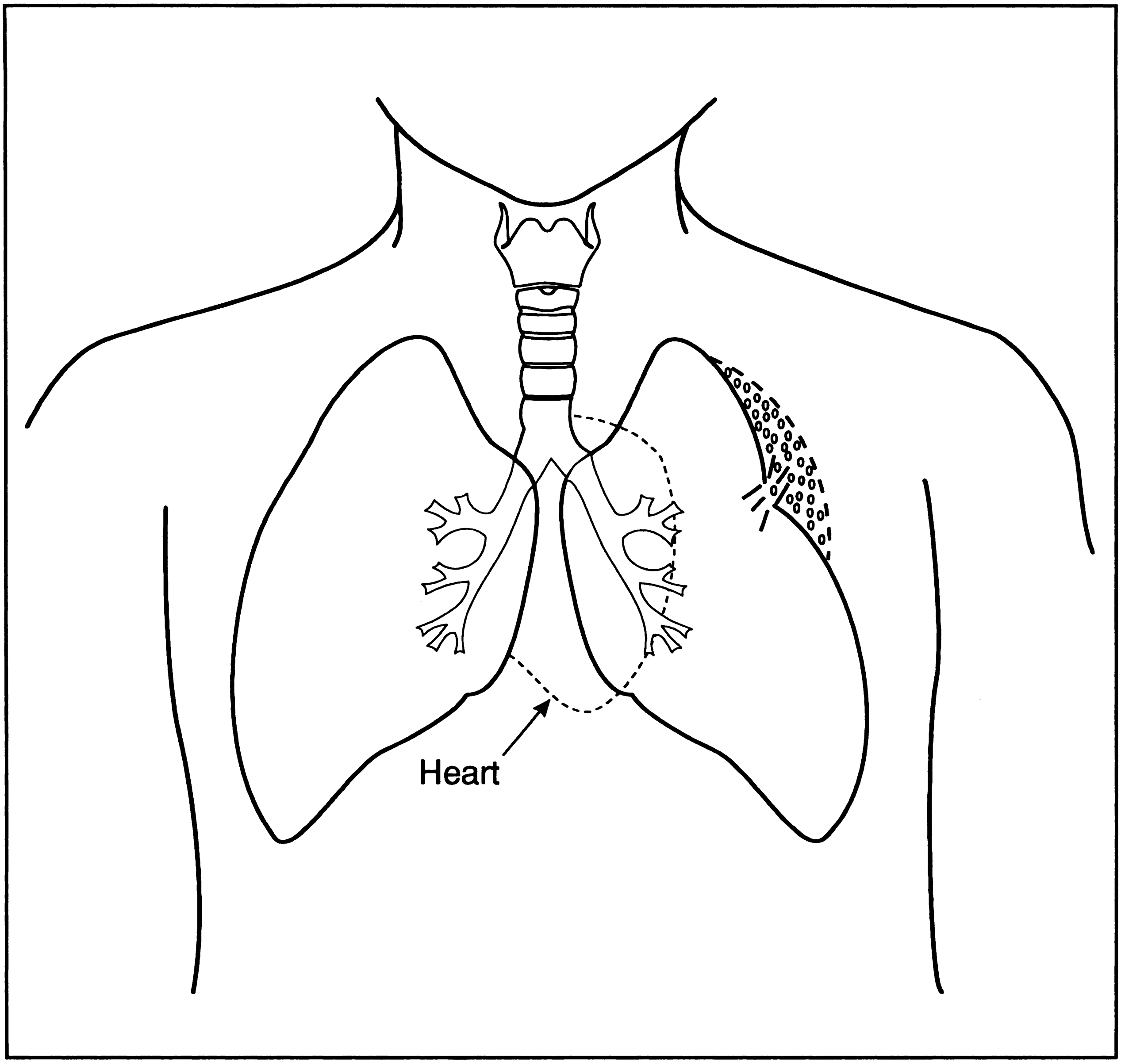


Figure 3-14. Pneumothorax.

under pressure, the air will expand during ascent according to Boyle's Law, creating a tension pneumothorax. The volume of air initially leaked into the pleural cavity and the remaining ascent distance will determine the diver's condition upon surfacing.

All cases of pneumothorax must be treated. This is sometimes done by removing the air with a catheter or tube inserted into the chest cavity. In cases of tension pneumothorax, this procedure may be lifesaving. Chapter Eight fully discusses the treatment of simple and tension pneumothorax.

3-8 INDIRECT EFFECTS OF PRESSURE

The conditions previously described occur because of 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 pressure of

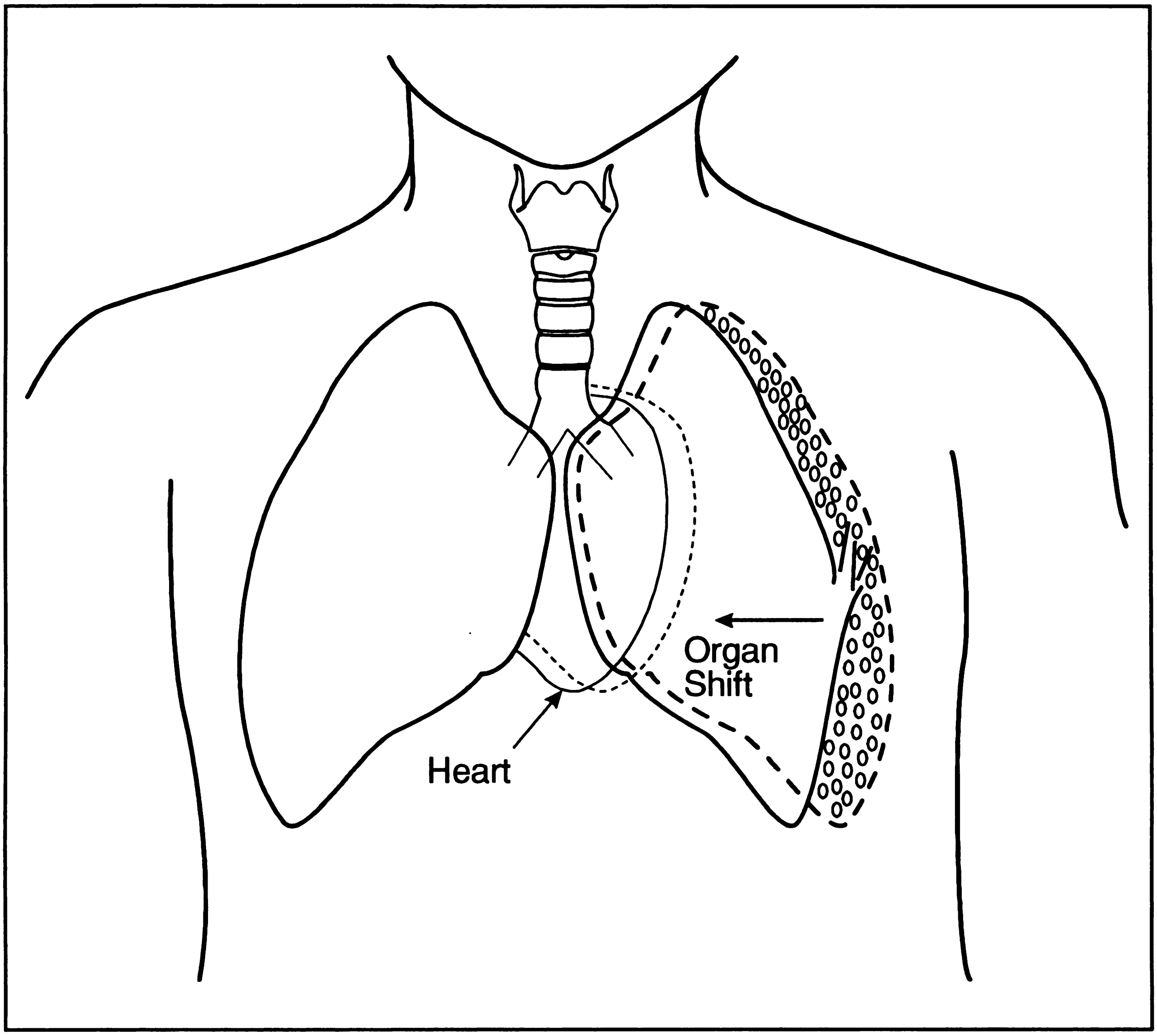


Figure 3-15. Tension Pneumothorax.

individual gases in the diver's breathing medium. The mechanisms of these effects include saturation and desaturation of body tissues with dissolved gas and the modification of body functions by abnormal gas partial pressures.

3-8.1 Nitrogen Narcosis. Narcosis is a state of stupor or unconsciousness caused by breathing inert gases at pressure while diving. The most common form, nitrogen narcosis, is caused by breathing compressed air at depth.

Inert gases vary in their narcotic potency. The effects from nitrogen may first become noticeable at depths exceeding 100 fsw, but become more pronounced at depths greater than 150 fsw. There is a wide range of individual susceptibility and some divers, particularly those experienced in deep operations with air, can often work as deep as 200 fsw without serious difficulty.

Narcosis involves confusion, impaired judgement, and a sense of well-being. Divers find it difficult to concentrate or to reason, and may not be able to remember what they are supposed to do or have already done. Performing even simple tasks is difficult. The signs of narcosis are:

- Loss of judgement or skill
- A false feeling of well-being
- Lack of concern for job or safety
- Apparent stupidity
- Inappropriate laughter

An uncontrollable desire of the diver to laugh, and a tingling and vague numbness of the lips, gums and legs are symptoms reported by divers who have experienced nitrogen narcosis.

Disregard for personal safety is the greatest hazard of nitrogen narcosis. Divers may display abnormal behavior such as removing the regulator or swimming to unsafe depths without regard to decompression sickness or air supply. There is no specific treatment for nitrogen narcosis; the diver must be brought to shallower depths where the effects are not felt.

Experienced and stable divers may be reasonably productive and safe at depths where others fail. They are familiar with the extent to which nitrogen narcosis impairs performance. They know that a strong conscious effort to continue the dive requires unusual care, time and effort to make even the simplest observations and decisions. Any relaxation of conscious effort can lead to failure or a fatal blunder.

Experience, frequent exposure to deep diving, and training may enable divers to perform air dives as deep as 180-200 fsw, but novices and susceptible individuals should remain at shallower depths. The performance or efficiency of divers breathing compressed air will be impaired at depths greater than 180 fsw. At 300 fsw or deeper, the signs and symptoms are severe and there is the possibility of hallucinations, bizarre behavior, or loss of consciousness. Furthermore, the associated increase in oxygen partial pressure at such depths may produce oxygen convulsions. Helium is widely used in mixed-gas diving as a substitute for nitrogen to prevent narcosis. Helium has not demonstrated narcotic effects at any depth tested by the U.S. Navy. Figure 3-16 shows the narcotic effects of compressed air diving.

3-8.2 Oxygen Toxicity. Partial pressure of oxygen in excess of that encountered at normal atmospheric conditions may be toxic to the body. Oxygen toxicity is dependent upon both partial pressure and exposure time. The two types of oxygen toxicity experienced by divers are Pulmonary Oxygen Toxicity and Central Nervous System (CNS) Oxygen Toxicity (also called high pressure oxygen poisoning).

3-8.2.1 Pulmonary Oxygen Toxicity. Low pressure oxygen poisoning, or Pulmonary Oxygen Toxicity, can begin to occur if more than 60-percent oxygen is breathed at one atmosphere for 24 hours or more. While diving, this can occur after a 24 hour exposure to ppO_2 of 0.6 ata (e.g., 60 fsw breathing air). Long exposures to higher levels of oxygen, such as administered during Recompression Treatment Tables Four, Seven and Eight may quickly lead to pulmonary oxygen toxicity. The symptoms of pulmonary oxygen toxicity may begin with a burning sensation on inspiration and progress to pain on inspiration. During recompression treatments, pulmonary oxygen toxicity may have to be tolerated in patients with severe neurological symptoms to effect adequate treatment. In conscious patients, the pain and coughing experienced with inspiration will eventually limit further exposure to oxygen. Return to normal pulmonary function will gradually occur after the exposure is terminated. Unconscious patients who receive oxygen treatments will not feel pain and it is possible to subject them to exposures resulting in permanent lung damage or pneumonia. For this reason, care must be

Nitrogen Narcosis	
Depth (fsw)	**Symptoms Include**
100	• Intoxicating effect similar to that of alcohol • Slowing of mental activity
150	• Slowing of reaction time and reflexes • General euphoria • Fixation of ideas
200	• Difficulty in concentrating or reasoning • Difficulty in remembering what to do or what has already been done
240	• Observations often inaccurate • Likely to make incorrect decision about what to do • Diver may not care about job or safety

Figure 3-16. Nitogen Narcosis.

taken when administering 100-percent oxygen (even at surface pressure) to unconscious patients.

3-8.2.2 Central Nervous System (CNS) Oxygen Toxicity. Central Nervous System (CNS) oxygen toxicity can occur when divers are exposed to more than 1.3 atmospheres of oxygen for a period of minutes to hours.

Susceptibility to central nervous system oxygen toxicity varies from person to person. Individual susceptibility will vary from time to time, and for this reason divers may experience CNS oxygen toxicity at exposure times and pressures previously tolerated. Because it is the partial pressure of oxygen itself that causes toxicity, the problem can occur when mixtures of oxygen with nitrogen or helium are breathed at depth. Oxygen toxicity is influenced by the density of the breathing gas and the characteristics of the diving system used. Thus, allowable limits for oxygen partial pressures differ to some degree when specific diving systems are discussed in later chapters. In general, oxygen partial pressures at or below 1.3 ata are unlikely to produce CNS toxicity. Closed system oxygen rebreathing systems require the lowest partial pressure limits, whereas surface-supplied helium-oxygen systems permit slightly higher limits.

Three major external factors contributing to the development of oxygen toxicity are the presence of a high level of carbon dioxide in the breathing mixture resulting from CO_2 absorbent failure,

CO_2 in the helmet supply gas, or inadequate ventilation during heavy exertion.

The most serious direct consequence of oxygen toxicity is convulsions. Sometimes recognition of early symptoms may provide sufficient warning to permit reduction in oxygen partial pressure and prevent the onset of more serious symptoms. The warning symptoms most often encountered include:

- Muscular twitching - Appears first in the lips or elsewhere in the face, but may affect any muscle.
- Nausea - May be intermittent.
- Spasmodic Vomiting
- Dizziness
- Abnormalities of vision or hearing - Tunnel vision (loss of ability to see things to the sides) is one of the more frequent visual symptoms.
- 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.
- Anxiety, confusion, irritability
- Unusual fatigue
- Incoordination, clumsiness

Symptoms may not always appear and most are not exclusively symptoms of oxygen toxicity. Twitching is perhaps the clearest warning of oxygen toxicity, but it may occur late, if at all. The appearance of any one of these symptoms usually represents a bodily signal of distress of some kind and should be heeded.

3-8.2.3 Convulsions. Convulsions, the most serious direct consequence of CNS oxygen toxicity, may occur suddenly without being preceded by any other symptom. During a convulsion, the individual loses consciousness and his brain sends out uncontrolled nerve impulses to his muscles. At the height of the seizure, all of the muscles are stimulated at once and lock the body into a state of rigidity. This is referred to as the tonic phase of the convulsion. The brain soon fatigues and the number of impulses slows. This is the clonic phase, and the random impulses to various muscles may cause violent thrashing and jerking for a minute or so. After the convulsive phase, brain activity is depressed and a post-convulsive (postictal) depression follows. During this phase, the patient is usually unconscious and quiet for a while, then semiconscious and very restless. He will then usually sleep on and off, waking up occasionally though still not fully rational. The depression phase sometimes lasts as little as 15 minutes, but an hour or more is not uncommon. At the end of this phase, the patient will often become suddenly alert and complain of no more than fatigue, muscular soreness, and possibly a headache. After an oxygen toxicity 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 postictal phase.

Despite its rather alarming appearance, the convulsion itself is usually not much more than a strenuous muscular workout for the victim. In an oxygen convulsion, the possible danger of hypoxia during breathholding in the tonic phase is greatly reduced because of the high partial pressure of oxygen in the tissues and brain. If a convulsion occurs in a recompression chamber, one tender should be able to keep the patient from thrashing against hard objects and being injured. Complete restraint of the patient's movements is neither necessary nor desirable. The oxygen mask shall be removed immediately. It is not necessary to force the mouth open to insert a bite block while a convulsion is taking place. After the convulsion subsides and the mouth relaxes, keep the jaw up and forward to maintain a clear airway until the diver regains consciousness. Breathing almost invariably resumes spontaneously.

Convulsions may lead to squeeze while surface-supplied helmet diving if the diver falls to a greater depth, but bruises and a chewed tongue are more likely the only consequences. Bringing a diver up rapidly during the height of a convulsion could possibly lead to gas embolism. When using SCUBA, the most serious consequence of convulsions is drowning. In this situation, using the buddy system can mean the difference between life and death.

The biochemical changes in the central nervous system caused by high oxygen partial pressures are not instantaneously reversed by reducing the oxygen partial pressure. If one of the early symptoms of oxygen toxicity occurs, the diver may still convulse up to a minute or two after being removed from the high oxygen breathing gas. One should not assume that an oxygen convulsion will not occur unless the diver has been off oxygen for two or three minutes.

If a diver with oxygen convulsions is prevented from drowning or causing other injury to himself, full recovery with no lasting effects occurs within 24 hours. Susceptibility to oxygen toxicity will not increase, although divers may be more inclined to notice warning symptoms during subsequent exposures to oxygen. However, this is most likely a psychological matter.

The actual mechanism of CNS oxygen toxicity remains unknown in spite of many theories and much research. Preventing oxygen toxicity is important to divers. When use of high pressures of oxygen is advantageous or necessary, divers should take sensible precautions, such as being sure the breathing apparatus is in good order, observing depth-time limits, avoiding excessive exertion, and heeding abnormal symptoms that may appear.

3-8.3 Absorption of Inert Gases. The average human body at sea level contains about one liter of dissolved nitrogen. All of the body tissues are saturated with nitrogen at a partial pressure equal to the partial pressure in the alveoli, about 570 mmHg (0.75 ata). If the partial pressure of nitrogen changes because of a change in the pressure of the composition of the breathing mixture, the pressure of the nitrogen dissolved in the body will gradually attain a matching level. Additional quantities will be absorbed or some of the gas will be eliminated, depending on the partial pressure gradient, until the nitrogen partial pressures in the lungs and in the tissues are in balance.

As described in Henry's Law, the amount of gas that will dissolve in a liquid is almost directly proportional to the partial pressure of that gas. If one liter of inert gas is absorbed at a pressure of one atmosphere, then two liters will be absorbed at two atmospheres, and three liters at three atmospheres, etc.

The process of taking up more nitrogen is called absorption or saturation. The process of giving up nitrogen is called elimination or desaturation. The chain of events is essentially the same in both of these processes even though the direction of exchange is opposite. In diving, both saturation (when the diver is exposed to an increased partial pressure of nitrogen at depth) and desaturation (when he returns to the surface) are important. The same processes occur with helium and other inert gases.

3-8.3.1 Saturation of Tissues. The sequence of events in the process of saturation can be illustrated by considering what will happen in the body of a diver taken rapidly from the surface to a depth of 100 feet (Figure 3-17). To simplify matters, we can say that the partial pressure of nitrogen in his blood and tissues on

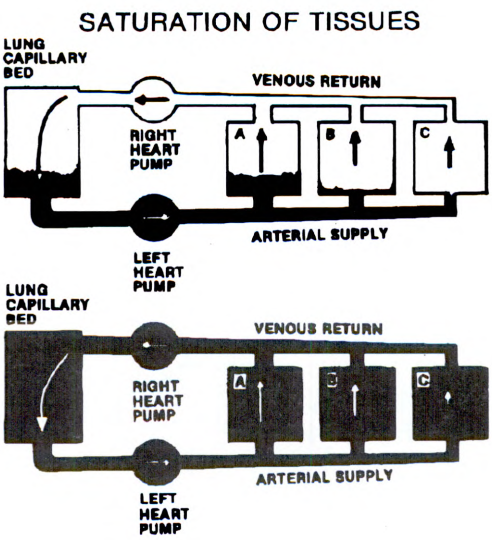


Figure 3-17. Saturation of Tissues. Shading in diagram indicates saturation with nitrogen or helium under increased pressure. Blood becomes saturated on passing through lungs, and tissues are saturated in turn via blood. Those with a large supply (as in A above) are saturated much more rapidly then those with poor blood supply (C) or an unusually large capacity for gas, as fatty tissues have for nitrogen. In very abrupt ascent from depth, bubbles may form in arterial blood or in "fast" tissue (A) even though the body as a whole is far from saturation. If enough time elapes at depth, all tissues will become equally saturated, as shown in lower diagram.

leaving the surface is roughly 0.8 ata. When the diver reaches 100 feet, his alveolar nitrogen pressure in his lungs will be about 0.8 x 4 ata or 3.2 ata, while the blood and tissues remain temporarily at 0.8 ata.

The partial pressure difference or gradient between the alveolar air and the blood and tissues is thus 3.2 - 0.8, or 2.4 ata. This gradient is the driving force which makes the molecules of nitrogen move by diffusion from one place to another. Consider the following events and factors in the diver at 100 feet:

- 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 pressure. It now has a nitrogen tension (partial pressure) of 3.2 ata and contains about four times as much nitrogen as before.

- 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.

- The volume of blood in a tissue is relatively small compared to the volume of the tissue, and the blood can carry only a limited amount of nitrogen. Because of this, the volume of blood which reaches a tissue over a short period of time loses its excess nitrogen to the tissue without greatly increasing the tissue nitrogen pressure.

- When the blood leaves the tissue, the venous blood nitrogen pressure is equal to the new tissue nitrogen pressure. When this blood goes through the lungs, it again reaches equilibrium at 3.2 ata.

- When the blood returns to the tissue, it again loses nitrogen until a new equilibrium is reached.

- As the tissue nitrogen pressure rises, the blood-tissue gradient decreases, slowing the rate of nitrogen exchange. The rate at which the tissue nitrogen partial pressure increases, therefore, slows as the process proceeds. However, each volume of blood that reaches the tissue gives up some nitrogen which increases the tissue partial pressure until complete saturation, in this case at 3.2 ata of nitrogen, is reached.

- Tissues that have a large blood supply in proportion to their own volume 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.

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

- At 100 feet, the diver's blood continues to take up more nitrogen in the lungs, and to deliver more nitrogen to tissues, until all tissues have reached saturation at a pressure of 3.2 ata of nitrogen. A few watery tissues that have an excellent blood supply will be almost completely saturated in a few minutes. Others, like fat with a poor blood supply and perhaps some watery tissues with an exceptionally meager blood flow, may not be completely saturated unless the diver is kept at 100 feet for 72 hours or longer.

- If kept at a depth of 100 feet until saturation is complete, the diver's body will contain about four times as much nitrogen as it did at the surface. Divers of average size and fatness will have about one liter of dissolved nitrogen at the surface and about four liters at 100 feet. Because fat holds about five times as much nitrogen as lean tissues, much of a diver's nitrogen content will be in his fatty tissue; an obese diver will contain considerably more nitrogen than a lean one.

- An important fact about nitrogen saturation is that the process will require the same length of time regardless of the nitrogen pressure involved. For example, if the diver had been taken to 33 feet instead of 100, it would have taken just as long to saturate him completely and to bring his nitrogen pressures to equilibrium. In this case, the original gradient between alveolar air and the tissues would have been only 0.8 ata instead of 2.4 ata. Because of this, the amount of nitrogen delivered to tissues by each round of blood circulation would have been smaller from the beginning. 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.

When any other inert gas, such as helium, is used in the breathing mixture, the body tissues will become saturated with that gas in the same process as for nitrogen. However, the time required to reach saturation will be different for each gas.

The actual total pressure of gases in a tissue may achieve significant supersaturation or subsaturation during the gas exchange when one gas replaces another in body tissues without a change in ambient pressure (isobaric gas exchange). This phenomenon requires careful consideration of the possible consequences of shifting inert gases during diving operations.

3-8.3.2 Desaturation of Tissues. The process of desaturation is the reverse of saturation (Figure 3-18). If the arterial pressure of the gas in the lungs is reduced, either through a change in pressure or a change in the breathing medium, the new pressure gradient will induce the nitrogen to diffuse from the tissues to the blood, from the blood to the gas in the lungs, and then out of the body with the expired breath. Some parts of the body will desaturate more slowly than others for the same reasons that they saturate more slowly: poor blood supply or a greater capacity to store gas.

There is a major difference between saturation

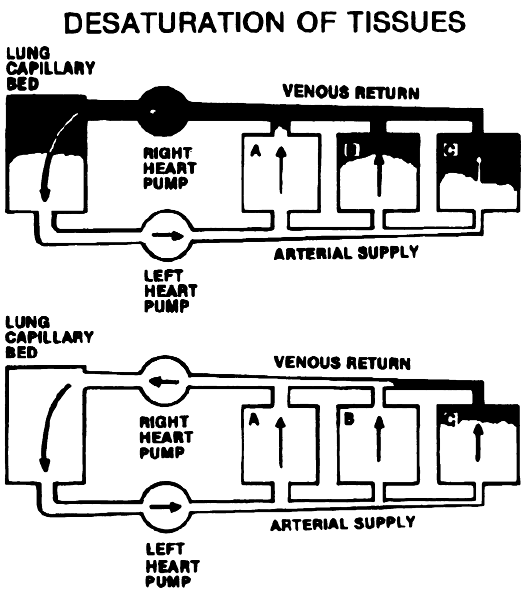


Figure 3-18. Desaturation of Tissues. The desaturation process is essentially the reverse of saturation. When pressure of inert gas is lowered, blood is cleared of excess gas as it goes through the lungs. Blood then removes gas from the tissues at rates depending on amount of blood that flows through them each minute. Tissue with poor blood supply (as in C in upper sketch) 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 each tissue, long decompression stops are required to desaturate the tissue enough so that bubbles will not form in it on ascent.

and desaturation. The body will accommodate large and relatively sudden increases in the partial pressure of the inspired gas without ill effect. The same is not true for desaturation, where a high pressure gradient (toward the outside) can lead to serious problems.

A diver working at a depth of 100 feet will be under a total pressure of 4 ata. The partial pressure of the nitrogen in the air he is breathing will be approximately 3.2 ata (80 percent of 4 ata). If his body is saturated with nitrogen, the partial pressure of the nitrogen in his tissues will also be 3.2 ata. If the diver were to quickly ascend to the surface, the total hydrostatic pressure on his tissues would be reduced to 1 ata, whereas the tissue nitrogen tension would remain momentarily at 3.2 ata.

A dissolved gas can have a tension higher than the total pressure in the body. If a tissue is supersaturated with gas to this degree, the gas will eventually separate from solution in the form of bubbles. Bubbles of nitrogen forming in the tissues and blood result in the condition known as decompression sickness. These bubbles can put pressure on nerves, damage delicate tissues, block the flow of blood to vital organs, and induce biochemical changes and blood clotting. Symptoms may range from skin rash to mild discomfort and pain in the joints and muscles, paralysis, numbness, hearing loss, vertigo, unconsciousness, and in extreme cases, death.

Fortunately, the blood and tissues can hold gas in supersaturated solution to some degree without serious formation of bubbles. This permits a diver to ascend a few feet without experiencing decompression sickness, while allowing some of the excess gas to diffuse out of the tissues and be passed out of his body. By progressively ascending in increments and then waiting for a period of time at each level, the diver will eventually reach the surface without experiencing decompression sickness.

3-8.4 Decompression. In most diving practice, with the exception of saturation diving, divers will not remain at depth long enough to become fully saturated with nitrogen. In a short dive, only tissues which saturate rapidly will absorb any appreciable quantity of the gas, and they will desaturate easily. The standard decompression tables, developed from the research of J.S. Haldane and various Navy test programs, have been written to provide procedures for controlled decompression for a wide range of diving circumstances. The factors involved include such considerations as depth and bottom time of the dive, and whether or not the diver has made more than one dive within a 12-hour period. All of these factors will have some influence upon the quantity of nitrogen which will have been absorbed. The established decompression table (Chapter Seven) must be followed rigidly to ensure maximum diver safety. Changes in decompression procedure shall be permitted only in cases of extreme emergency under the advice of a Diving Medical Officer, with the approval of the Commanding Officer.

Not all decompression is carried out by staged ascent to the surface. If the depth of the dive and the bottom time are less than established values, decompression stops or staged decompression is not required. These are No-Decompression Dives. Also, within certain limits, a diver can be brought out of the water, repressurized in a recompression chamber, and then decompressed on the surface. This is called Surface Decompression. These surface decompression procedures are useful when the surface support unit must move quickly, or when the in-water conditions are hazardous and dictate that it would be better to remove the diver from the water.

This procedure can also be used to increase diver productivity during a diving operation. By using surface decompression procedures, one set of divers can be completing decompression in the recompression chamber, while another set is on the bottom working, rather than waiting until the first set of divers have completed their in-water decompression.

Oxygen decompression uses gradients of partial pressure differences between the tissues and the alveolar air that cause desaturation of the tissues. It is the difference between tissue gas tension (partial pressure) and the total external pressure on the body that is involved in bubble formation. If this distinction is understood, the principle of oxygen decompression should be clear. If the diver breathes oxygen during his decompression stops, the inert gas pressure in his alveoli will be reduced to nearly zero. This produces the largest possible outward gradient for the inert gas and brings it 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 formation of bubbles is no more likely than it would be if the diver was breathing air 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, and it is frequently not practical to supply a diver with oxygen. However, oxygen decompression is an integral part of helium-oxygen surface-supplied diving techniques, and is used routinely in connection with surface decompression.

Oxygen mixtures that contain a higher concentration of oxygen than that of air can sometimes be used as the breathing medium to reduce the required decompression time. 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 100 feet pointed out that his blood and tissues tend to reach equilibrium with the 3.2 ata partial pressure of nitrogen in his alveoli. If the diver breathed a mixture of 60-percent nitrogen, 40-percent oxygen at 100 feet instead of air, the nitrogen pressure in his alveoli would be about 2.4 ata. This is the nitrogen pressure normally present when breathing air at 66 feet. With this breathing medium, a 100-foot dive would require the shorter decompression time of an air dive to 70 feet.

Oxygen-rich mixtures increase the oxygen tension in the alveolus, resulting in an increased arterial oxygen tension that is almost the same magnitude as the decreased nitrogen tension. Because oxygen is rapidly consumed by body tissue, the resulting increase in tissue tension is insignificant. Thus, not only has the tissue nitrogen tension been decreased, but the total tissue gas tension has been decreased as well. The increased inspired oxygen contributes little to tissue supersaturation and bubble formation; it is the inert gas (nitrogen or helium) tension that is important.

The extent to which oxygen-rich mixtures can be used is limited by the fact that the partial pressure of oxygen is increased, and exposure to oxygen must be kept within safe limits of both pressure and time. Helium-oxygen diving techniques normally involve the use of mixtures containing as much oxygen as is considered safe for the dive involved in order to keep decompression time to the minimum. Therefore, the mixture principle is routinely applied in helium-oxygen diving.

Although all U.S. Navy decompression procedures have been tested extensively in the laboratory to an acceptable level of risk, field adherence to procedures and compliance with the standard tables does not guarantee that a diver will avoid decompression sickness. There are a number of individual differences and environmental factors that may influence development of decompression problems, in spite of all precautions. These factors include age, degree of obesity, cold, excessive fatigue, lack of sleep, hydration, nutrition, alcoholic indulgence, or anything that, in general, contributes to poor physical condition or poor circulatory efficiency. Unusually heavy exertion during the dive and extremes of temperature also can have unfavorable effects. Exercise during decompression, although it hastens elimination of inert gas from some tissues, may increase the incidence of decompression sickness. In addition, individual susceptibility may cause decompression sickness in healthy, fit divers who have no apparent predisposing conditions.

3-8.5 Decompression Sickness. As has been discussed, when a diver's blood and tissues have taken up nitrogen or helium in solution at depth, reducing the external pressure on ascent can produce a state of supersaturation, as has been discussed. If the elimination of dissolved gas, via the circulation 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 can no longer stay in solution. The situation then resembles what happens when a bottle of carbonated beverage is uncapped.

Supersaturated tissues may result in bubble formation in tissue or in the bloodstream. Also, bubbles may arise from the lung and enter the bloodstream from pulmonary overinflation (arterial gas embolism). Once in the bloodstream these bubbles will cause symptoms depending only on where they end up, not on their source. These bubbles may exert their effects directly in several ways:

- Direct blockage of arterial blood supply leading to tissue hypoxia, tissue injury and death. This is called embolism and may occur from pulmonary damage (arterial gas embolism) or from the bubbles reaching the arterial circulation during decompression. The mechanism usually causes cerebral (brain) symptoms.

- Venous congestion from bubbles or slow blood flow and sludging, which leads to increased back pressure. This increased back pressure leads to hypoxia, tissue injury and death. This is one of the mechanisms of injury in Spinal Cord DCS.

- Direct pressure on surrounding tissue (autochthonous bubbles) causing stretching, pressure on nerve endings or direct mechanical damage. This is another mechanism for Spinal Cord DCS and may be a mechanism for Musculoskeletal DCS.

- Bubbles blocking blood flow in the lungs that leads to decreased gas exchange, hypoxia and hypercarbia. This is the mechanism of damage in Pulmonary DCS.

The time course for these Direct Bubble Effects is short (a few minutes to hours). The only ***necessary*** treatment for Direct Bubble Effects is recompression. This will compress the bubble to a smaller diameter. This restores blood flow, decreases venous congestion and improves gas exchange in the lungs and tissues. It also increases the speed at which the bubbles outgas and collapse.

Bubbles may also exert their effects indirectly because a bubble present in a blood vessel acts like a foreign body. The body reacts as it would if there were a cinder in the eye or a splinter in the hand. The body's defense mechanisms become alerted and try to reject the foreign body. This try at rejection includes the following:

- Blood vessels become "leaky" (secondary to chemical release). Blood plasma leaks out while blood cells remain inside. The blood becomes thick and causes sludging and decreased pressure downstream, with possible shock.

- The platelet system becomes active and the platelets gather at the site of the bubble causing a clot to form.

- The coagulation system becomes active and the blood around the area of the bubble begins to coagulate and clot at the site.

- The injured tissue releases fats that clump together in the bloodstream. This acts as emboli, causing tissue hypoxia.

- Injured tissues release histamine and histamine-like substances, causing edema, which leads to allergic-type problems of ***shock and respiratory distress.***

Bubble Reaction takes place in a longer period (up to 30 minutes or more) than the direct effects. Because the non-compressible clot replaces a compressible bubble, recompression alone is not enough. To restore blood flow and relieve hypoxia, hyperbaric treatment and adjunctive therapy are the primary treatments for this phase of bubble disease.

The resulting symptoms depend on the location and size of the bubble or bubbles. Symptoms include pain in joints, muscles, or bones when a bubble is in one of these structures. Bubble formation in the brain can produce blindness, dizziness, paralysis, and even unconsciousness and convulsion. When the spinal cord is involved, paralysis and/or loss of feeling can occur. Bubbles in the inner ear produce hearing loss and vertigo. Bubbles in the lungs can cause cough, shortness of breath, and hypoxia, a condition referred to as "the chokes". This condition often proves fatal. Skin bubbles produce itching or rash or both. Unusual fatigue or exhaustion after a dive is probably also due to bubbles in unusual locations, and biochemical changes they have induced. 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 lead to local damage if not treated, but life is seldom threatened.

Treatment of decompression sickness is accomplished by recompression. This involves putting the victim back under pressure to reduce the size of the bubbles to cause them to go back into solution, and to supply extra oxygen to the hypoxic tissues. Treatment is done in a recompression chamber, but can sometimes be accomplished in the water if a chamber cannot be reached in a reasonable period of time. Recompression in the water is not recommended, but if undertaken, must be done following specified procedures. Further discussion of the symptoms of decompression sickness and a complete discussion of treatment are presented in Chapter Eight.

Modern research has shown that the symptoms caused by bubbles depend on their ultimate location and not their source. Bubbles entering the arterial circulation from the lung (pulmonary overinflation syndrome) will have exactly the same effects as those arising from decompression sickness which find their way into the arterial circulation. This means that the treatment of diseases caused by bubbles is dependant on the ultimate symptoms and symptom severity, and not on the source of the bubbles. This has lead to new treatment protocols in which the initial treatment for arterial gas embolism and decompression sickness is the same, recompression to 60 fsw. After that treatment proceeds according to the patient's condition and response to therapy. Many agree with the opinion that Direct Bubble Effects are the cause of symptoms occurring early after surfacing. These cases usually respond to recompression alone. However, the longer after surfacing that symptoms appear, or the longer period elapsing after symptoms appear and treatment begins, the more likely the effect of the bubbles is responsible. In this situation, recompression alone will be less effective.

Prevention of decompression sickness is generally accomplished by following the decompression tables. However, individual susceptibility or unusual conditions, either in the diver or in connection with the dive, will produce a small percentage of cases even when proper dive procedures are followed meticulously. To be absolutely free of decompression sickness 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 must not be taken to mean that the tables contain an unnecessarily large safety factor. The tables represent the minimum workable decompression time which will permit average divers to surface safely from normal working dives without an unacceptable incidence of decompression sickness.

3-8.6 High Pressure Nervous Syndrome (HPNS). High Pressure Nervous Syndrome (HPNS) is a derangement of central nervous system function that occurs during deep helium-oxygen dives, particularly saturation dives. The cause is unknown. The clinical manifestations include nausea, fine tremor, imbalance, incoordination, loss of manual dexterity, and loss of alertness. Abdominal cramps and diarrhea develop occasionally. In severe cases a diver may develop vertigo, extreme indifference to his surroundings, and marked confusion such as inability to tell the right hand from the left hand. HPNS is first noted between 400 and 500 feet, and the severity appears to be both depth and compression rate dependent. With slow compression, depths of 1000 feet may be achieved with relative freedom from HPNS. Beyond that, some HPNS may be present regardless of the compression rate. Attempts to block the appearance of the syndrome have included the addition of nitrogen or hydrogen to the breathing mixture and the use of various drugs. No method appears to be entirely satisfactory.

3-8.7 Compression Pains. Compression pains (referred to as compression arthralgia) result from increases in external pressure surrounding the body. These pains affect the joints and may occur in almost any diver. They have been experienced in the knees, shoulders, fingers, back, hips, neck, and ribs. Compression pains are often deep aching pains, similar to those of Type I decompression sickness. However, the pains may be relatively sudden in onset and initially intense. These pains may be accompanied by "popping" of joints or a dry, "gritty" feeling within the joint.

Symptoms are dependent on depth, rate of compression, and individual susceptibility. While primarily a problem encountered in saturation diving, symptoms may occur as shallow as 100 feet at rapid compression rates, such as seen in air diving. In deep, helium saturation dives with slower compression rates, symptoms are more commonly seen deeper than 300 feet. Deeper than 600 feet, compression pains may occur even at very slow rates of compression. These pains may be severe enough to limit diver activity, travel rate, and depths during downward excursions. Improvement is generally noted as time is spent at depth but, on occasion, these pains may last well into the decompression phase of the dive until shallower depths are reached. They can be distinguished from decompression sickness pain because they were present before decompression was started and do not increase in intensity with decreasing depth.

The mechanism of compression pain is unknown, but is thought to result from the sudden increase in tissue gas tension surrounding the joints causing fluid shifts and interfering with joint lubrication.

3-9 PHYSIOLOGICAL HAZARDS FROM MUNITIONS

Divers frequently work with explosive material or are involved in combat swimming and therefore may be subject to the hazards of underwater explosions. An explosion is the violent expansion of a substance caused by the gases released during rapid combustion. One effect of an explosion is a shock wave that travels outward from the center, somewhat like the spread of ripples produced by dropping a stone into a pool of water. This shock wave moving through the surrounding medium (whether air or water) passes along some of the force of the blast.

A shock wave moves more quickly and is more pronounced in water than in air because of the relative incompressibility of liquids. Because the human body is mostly water and incompressible, an underwater shock wave will pass through the body with little or no damage to the solid tissues. However, the air spaces of the body, even though they may be in pressure balance with the ambient pressure, will not readily transmit the overpressure of the shock wave. As a result, the tissues that line the air spaces will be subject to a violent fragmenting force at the interface between the tissues and the gas.

The amount of damage to the body is influenced by a number of factors. These include the size of the explosion, the distance from the site, and the type of explosive (because of the difference in the way the expansion progresses in different types of explosives). In general, larger, closer, and slower developing explosions are more hazardous. The depth of water and the type of bottom (which can reflect and amplify the shock wave) may also have an effect. Under average conditions, a shock wave of 300 psi (21.09 kg/cm^2) or greater will cause injury to the lungs and intestinal tract. A diver 48 feet (15 meters) from the blast would experience a shock wave of this magnitude from the explosion of a 1.36 pound charge.

The extent of injury will also be determined in part by the degree to which the diver's body is submerged. For an underwater blast, any part of the body which is out of the water will not be affected. Conversely, for an air blast, greater depth provides more protection. The maximum shock pressure to which a diver should be exposed is 50 psi. The safest and recommended procedure is to have all divers leave the water if an underwater explosion is planned or anticipated. A diver who anticipates a nearby underwater explosion should try to get all or as much of his body as possible out of the water. If in the water, the diver's best course of action is to float face up, presenting the thicker tissues of the back to the explosion.

3-10 BODY TEMPERATURE, HEAT LOSS, AND OTHER PHYSIOLOGICAL PROBLEMS IN DIVING

In addition to decompression, thermal problems arising from exposure to cold water pose the major consideration when planning operational dives and selecting equipment. The working diver commonly experiences heat loss during immersion and often expects to be uncomfortably chilled at the end of a dive. Bottom time limits may be determined by the diver's cold tolerance rather than by decompression considerations.

The human body functions effectively within a relatively narrow range of internal temperature. The average, or normal, core temperature of 98.6°F (37°C) is maintained by natural mechanisms of the body, aided by artificial measures such as the use of protective clothing or air conditioning when external conditions tend toward cold or hot extremes. Rewarming before a repetitive dive is as important as calculating residual nitrogen levels (Chapter 7).

When the body temperature is reduced below normal, gas absorption increases. This requires modification of decompression procedures by selecting a decompression table appropriate for the next longer or deeper dive schedule.

3-10.1 Body Temperature Regulation. The metabolic processes of the body constantly generate heat. If heat is allowed to build up inside the body, damage to the cells can occur. To maintain internal temperature at the proper level, the body must lose heat equal to the amount it produces.

Heat transfer is accomplished in several ways. The blood, while circulating through the body, picks up excess heat and carries it to the lungs where some of it is lost with the exhaled breath. Heat is also transferred to the surface of the skin, where much of it is dissipated through a combination of conduction, convection, and radiation. Moisture released by the sweat glands cools the surface of the body as it evaporates, and speeds the transfer of heat from the blood to the surrounding air. If the body is working hard and generating greater than normal quantities of heat, the blood vessels nearest the skin will dilate to permit more of the heated blood to reach the body surfaces, and the sweat glands will increase their activity.

Maintaining proper body temperature is particularly difficult for a diver working underwater. The principal temperature control problem encountered by divers involves keeping the body warm. The high thermal conductivity of water, coupled with the normally cool-to-cold waters in which divers operate, can result in rapid and excessive heat loss.

3-10.1.1 Excessive Heat Loss (Hypothermia). When cold water enters a dry suit or a wet suit, the diver experiences a sudden drop in skin temperature. If a diver with no thermal protection is suddenly plunged into very cold water, the effects are immediate and rapidly disabling. The diver gasps, and his respiratory rate and tidal volume increase. His breathing becomes so rapid and uncontrolled that he cannot coordinate his breathing and swimming movements. This lack of breathing control makes survival in rough, cold water very unlikely.

A water temperature of approximately 91°F (33°C) is required to keep an unprotected, resting man at a stable temperature. The unprotected diver will be affected by excessive heat loss and become chilled within a short period of time in water temperatures below 72°F (23°C). As his body temperature falls, the diver first feels uncomfortable, and then, as his body tries to increase heat production in the muscles, shivering begins. If cooling continues, his ability to perform useful work becomes seriously impaired; his sense of touch is dulled and his hands lose dexterity. As shivering intensifies, it brings on a general lack of coordination and a SCUBA diver may experience difficulty keeping his mouthpiece in place. He soon loses his ability to think clearly and finds it increasingly difficult to concentrate.

At extremely low temperatures or with prolonged immersion, body heat loss will reach a point at which death will occur. Appropriate dress can greatly reduce the effects of heat loss, and a diver with proper dress can work in very cold water for reasonable periods of time.

Inhaled gases are heated in the upper respiratory tract. More energy is required to heat the denser gases encountered at depth. Thus, heat loss through the respiratory tract becomes an increasingly significant factor in deeper diving. In fact, respiratory shock can develop if a diver breathes unheated gas while making deep saturation dives at normal water temperature. The body's ability to tolerate cold environments is due to natural insulation and a built-in means of heat regulation. Temperature is not uniform throughout the body. It is more accurate to consider the body in terms of an inner core where a constant or uniform temperature prevails, and a superficial region through which a temperature gradient exists from the core to the body surface. Over the trunk of the body, the thickness of the superficial layer may be one inch (2.5 cm). The extremities become a superficial insulating layer when their blood flow is reduced to protect the core.

Once in the water, heat loss through the superficial layer is lessened by the reduction of blood flow to the skin. The automatic, cold-induced vasoconstriction (narrowing of the blood vessels) lowers the heat conductance of the superficial layer and acts to maintain the heat of the body core. Unfortunately, vasoconstrictive regulation of heat loss has only a narrow range of protection. When the extremities are initially put into very cold water, vasoconstriction occurs and the blood flow is reduced to preserve body heat. After a short time, the blood flow increases and fluctuates up and down for as long as the extremities are in cold water. As circulation and heat loss increase, the body temperature falls, and may continue falling, even though heat production is increased by shivering.

Much of the heat loss in the trunk area is transferred over the short distance from the deep organs to the body surface by physical conduction, which is not under any physiological control. Most of the heat lost from the body in moderately cold water is from the trunk and not the limbs.

Exercise normally increases heat production and body temperature in dry conditions. Paradoxically, exercise in cold water may cause the body temperature to fall more rapidly. Any movement which stirs the water in contact with the skin creates turbulence that carries off heat (convection). Heat loss is not caused only by convection at the limbs, but also by increased blood flow into the limbs during exercise. Continual movement causes the limbs to resemble the internal body core rather than the insulating superficial layer. These two conflicting effects result in the core temperature being maintained or increased in warm water and decreased in cold water.

Increased heat production requires an equivalent increase in oxygen consumption. The respiratory minute volume of the lungs must increase by the same magnitude. If a diver is breathing nine liters of air per minute at rest in the water and becomes chilled, his heat production may increase three times to compensate for chilling. His respiratory ventilation will then increase to 36 liters per minute. In this example, the diver would have the same air consumption at rest keeping warm as when performing moderate work in warm water.

All of these factors work against the diver. Even his body's natural insulation and protective function give way to cold water. The diver's thinking ability becomes impaired, and the effect of this impairment on the use of his hands and other motor functions may prevent him from choosing and executing the best procedures to complete a task. In some cases, his survival may be at stake.

The signs and symptoms of dropping body core temperature, from the first noticeable effects to death, are listed in Table 3-1. The treatment for hypothermia is discussed in Chapter 8.

Table 3-1. Signs and Symptoms of Dropping Core Temperature.

Core Temperature °F	°C	Symptoms
98.6	37	Cold sensations, Skin vasoconstriction, Increased muscle tension, Increased oxygen consumption
97	36	Sporadic shivering suppressed by voluntary movements, Gross shivering in bouts, Further increase in oxygen consumption, Uncontrollable shivering
95	35	Voluntary tolerance limit in laboratory experiments, Mental confusion, Impairment of rational thought, Possible drowning, Decreased will to struggle
93	34	Loss of memory, Speech impairment, Sensory function impairment, Motor performance impairment
91	33	Hallucinations, delusions, partial loss of consciousness, In shipwrecks and survival history, 50% do not survive, Shivering impaired
90	32	Heart rhythm irregularities, Motor performance grossly impaired
88	31	Shivering stopped, Failure to recognize familiar people
86	30	Muscles rigid, No response to pain
84	29	Loss of consciousness
80	27	Ventricular fibrillation (ineffective heartbeat), Muscles flaccid
79	26	Death

3-10.1.2 Excessive Heat (Hyperthermia)

Diving in areas such as the Middle East may expose a diver to heat stress both in and out of the water. Pre-dive heat exposure may lead to significant dehydration putting the diver at risk once he enters the water. This would be especially true if a protective suit has to be worn because of marine life or contaminated water which is warm. Specific guidelines based on temperature/time exposures are not available at this time but hyperthermia should be considered a potential risk anytime air temperature exceeds 90°F and water temperature is above 82°F.

The magnitude of heat stress imposed on a diver will depend on water temperature, duration of the dive, thermal protection garmet and the raste at which the diver is working. Heat stress is related to how much the body core temperature rises. An individual is considered to have developed hyperthermia when core temperature rises 1.8°F (1°C) above normal (98.6°F, 37°C). The maximum body core temperature considered safe is 102.2°F (39°C). A diver wearing a wet suit in cool water while performing hard work, can reach this upper limit, as can a diver wearing no thermal protection in warmer water and working at a lower rate. If during work a diver feels hot and uncomfortable, then he should consider decreasing his work rate or limiting his exposure.

Individual differences will affect development of hyperthermia. Individuals with higher levels of physical fitness and lower levels of body fat will be less likely to develop hyperthermia. Drinking adequate amounts of fluid will reduce the risk compared to dehydrated divers. Alcohol or caffeine beverages should be avoided since they can produce dehydration. Medications containing antihistamines or asprin should not be used in warm water diving. Age (20-40 years old), sex and race do not alter the risk of hyperthermia. Risk of acute oxygen toxicity may increase in warm water diving where 100% oxygen is breathed, so precautions should be heightened. There is no evidence that warm water diving will increase the risk of decompression sickness.

Acclimatization is the process where repeated exposures to heat will reduce (but not eliminate) the rise in core temperature. At least five consecutive days of acclimatization to warm water diving are needed to see an increased tolerance to heat. Excercise enhances the rate of acclimation. Where possible, acclimatization should be done before attempting long duration working dives. Acclimation should begin with shorter exposures and lighter workloads. All support personnel should also be heat acclimatized. Fully acclimatized divers can still develop hyperthermia. Benefits of acclimatization will begin to disappear in 3-5 days after stopping exposure to warm water. Acclimatization can be maintained by diving or swimming in warm water on days when a diver is not scheduled for a working dive.

Signs and symptoms of hyperthermia can vary among individuals. Since a diver might have been in water that may not be considered hot, support personnel must not rely solely on classical signs and symptoms of heat stress for land exposures.

Table 3-2 lists commonly encountered signs and symptoms of heat stress in diving.

Table 3-2. Common Signs and Symptoms of Heat Stress Encountered in Diving.

Least Severe	High breathing rate
	Feeling of being hot, uncomfortable
	Low urine output
	Inability to think clearly
	Erratic swim or work pattern
	Fatigue
	Light-headed or headache
	Nausea
	Muscle cramps
	Sudden rapid increase in pulse rate
	Disoriented, confused
	Exhaustion
	Collapse
Most Severe	Death

Breathing rates higher than normally expected, for the rate of work, are an early warning of hyperthermia. Excessive breathing rates, maintained for more than 1-2 minutes, can produce light-headedness, muscle twitching, headache or unconsciousness.

Mental abilities begin to deteriorate with core temperatures greater than 100.5°F. The ability to learn and retain new information will be impared. Swimming patterns or work behavior may become progressively more erratic. By the time the diver's core temperature approaches 102°F noticeable mental confusion may be present.

The likelihood of hyperthermia increases with dive time. Dehydration may occur mainly through sweating; urination may be absent. a two-pound weight loss after a dive indicates a loss of one-quart of body water. Losses greater than four-pounds indicate marked dehydration. Muscle cramps may develop. A rapid increase in pulse rate can indicate severe hyperthermia. Divers may experience sensation of being hot, fatigued, disoriented or nauseated before they collapse. Collapse may occur suddenly, without prior warning signs.

Divers may appear physically functional in the water, but collapse when they exit the water. Therefore, all divers who have been in the water for more than an hour should be assisted out of the water and monitored carefully. If the feel lightheaded when standing, they should lie down, receive adequate rehydration and cease diving until the next day.

Like hypothermia, hyperthermia can be insidious and cause problems without the diver being aware of it. Acclimatization, adequate hydration, experience and common sense all play a role in preventing hyperthermia. Shelter personnel from the sun, keep the amount of clothing worn to a minimum. Adequate pre-dive hydration is essential. Urinating 1-2 times per hour, where urine is pale and clear, usually indicates adequate hydration. Stand-by divers and support personnel should consume about one quart of fluid per hour in hot environments. Frequent rest periods are advised.

3-10.2 Dehydration. Dehydration is a concern to divers, particularly in temperate zones. It is defined as an excessive loss of water from the body tissues and is accompanied by a disturbance in the balance of essential electrolytes, particularly sodium, potassium, and chloride. This loss of water can occur through excessive perspiration or long periods of breathing dry gases.

Immersion in water creates a condition resembling a gravity-free state. The weight of the body and the hydrostatic gradient in the circulatory system are almost exactly counterbalanced by the ambient water pressure. This reduces the volume of pooled blood in the leg veins and results in an increase in central blood volume, leading to water diuresis (immersion diuresis).

After entering the water, many people experience an increased urine flow which seems to be related to both cardiovascular and hormonal changes that occur during diving. The increased urine flow leads to increasing loss of water from the body during the dive. Dehydration is felt to predispose the incidence of decompression sickness. Prevention is the best medicine. Divers should keep themselves well hydrated by increasing their fluid intake during diving operations.

3-10.3 Hypoglycemia. Hypoglycemia is an abnormally low blood sugar (glucose) level. It is a condition that is not due to respiratory difficulties, but can complicate or be confused with them. Sugar, derived from food, is the body's main fuel. It is carried to the tissues by the blood, and if the blood level falls, tissue function will be affected.

The brain is especially sensitive to lack of glucose. 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, oxygen toxicity, and arterial gas embolism. Some of the more common symptoms are unusual hunger, excessive sweating, numbness, chills, headache, trembling, dizziness, confusion, incoordination, anxiety, and fainting. In severe cases, loss of consciousness and convulsions may occur.

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 frequently. Severe exercise on an empty stomach will occasionally bring on the symptoms even in a person who ordinarily has no abnormality in this respect. Normally, the body secretes insulin which promotes the use and storage of glucose. People with diabetes do not secrete enough insulin and have an excess of glucose in their blood. They must take insulin by injection to avoid the symptoms of the disease and to keep their blood sugar at a normal level. If they take too much, or if some factor such as unexpectedly hard work reduces the amount needed, serious hypoglycemia can develop rapidly. For this reason diabetics are considered bad risks in diving.

In diving, the possibility of hypoglycemia increases during long, drawn out diving operations. Personnel have a tendency to skip meals or eat haphazardly during the operation. For this reason, prevention through proper nutrition is the best medicine. Prior to long, cold, arduous dives, divers should be encouraged to carbohydrate load. For more information, see Naval Medical Research (NMRI) Report 89-94. A diver who often experiences definite weakness (or other symptoms mentioned) when he misses meals, should have a physical examination to determine whether hypoglycemia is the cause and if he is particularly susceptible to it. If hypoglycemia is present, giving sugar by mouth (or if the victim is unconscious, intravenous glucose) will relieve the symptoms promptly and prove the diagnosis.

CHAPTER FOUR

OPERATIONS PLANNING

4-1 INTRODUCTION

The Navy diving program is a regulated program in which qualified divers use certified and authorized equipment and approved procedures. The Chief of Naval Operations OPNAV Instructions 3150 series and the Naval Sea Systems Command NAVSEA Instructions 3150 series provide the basic operational guidance for the Navy diving program. The *U.S. Navy Diving and Manned Hyperbaric System Safety Certification Manual*, NAVSEA SS-521-AA-MAN-010, provides the basic guidance for certification of diving equipment and hyperbaric systems. All U.S. Navy diving activities operate in accordance with these directives.

This chapter provides a comprehensive guide to effective dive planning for any size operation. The material is organized into paragraphs which form the normal sequence of steps in the planning process (Figure 4-1). The chapter also presents a series of worksheets and checklists to assist in planning specific operations (see Paragraphs 4-10.3 and 4-10.5). The subject of record keeping and reporting, which is a continuing responsibility at all stages of an operation, is covered in Paragraph 4-11 and Appendix E.

Operations Planning Steps

1.	Define Mission Objectives
2.	Identify Operational Tasks
3.	Collect and Analyze Data
4.	Select Diving Technique
5.	Select Equipment and Supplies
6.	Select and Assemble Diving Team
7.	Organize and Schedule Operations
8.	Brief Diving Team
9.	Make Final Preparations and Check All Safety Precautions
10	Start Operation

Figure 4-1. Steps in Planning of Diving Operations.

4-2 PLANNING CONSIDERATIONS

The success of any diving mission is a direct outcome of careful, thorough planning. The nature of each operation determines the scope of the planning effort, but certain considerations apply to every operation:

- Bottom time is always at a premium and any preplanned measures that conserve bottom time or increase diver effectiveness shall be given high priority.

- An operation that is delayed due to unanticipated problems may become a failure. Careful planning of the time available to accomplish specific objectives is a prerequisite to success.

- Equipment must be appropriate for the mission.

- Diving operations shall not be conducted under extreme environmental conditions or when the safety of personnel or support facility will be unnecessarily placed at risk.

- Divers must be given protection from shipping hazards, extremes of temperature, and dangerous pollution during all operations.

- The availability of emergency assistance from a diving unit or from outside sources must be coordinated and verified in advance.

- Diving operations are very dependent on weather conditions. Planning should always consider worst case scenarios.

These considerations must be weighed against the urgency of the dive mission.

4-3 DEFINE MISSION OBJECTIVE

A clear statement of the mission objective must be established. The mission objective statement should be concise.

> **Example:** Locate, recover, and deliver lost anchor to USS SMITH at Pier A.

If the degree of urgency of the mission objective is unclear to the officer planning the operation, clarification shall be obtained from the tasking authority to determine acceptable risks.

Tasks to be accomplished by diving teams shall be listed and defined. Work items that must be coordinated with other support teams should be identified.

4-4 IDENTIFY OPERATIONAL TASKS

With the objectives of the operation defined, a basic outline for an operation can be prepared. For all operations, each task shall be identified and placed in the context of an overall schedule or job profile. This section defines and outlines the primary diving functions that may be identified in an operational task. These functions may be incorporated singly or in conjunction with others.

4-4.1 Underwater Ship Husbandry (UWSH). Underwater Ship Husbandry is defined as the waterborne inspection, maintenance, and permanent repair of Navy hulls and hull appendages while those hulls are waterborne. Most fleet diving operations are conducted to accomplish UWSH and include such diverse tasks as waterborne hull cleaning, underwater weld repair to ship's hulls and appendages, propeller replacement, underwater hull inspection, and non-destructive testing. Through the application of UWSH procedures, ship maintenance is accomplished quicker and more economically by eliminating the requirement to drydock a ship. Through regular waterborne maintenance, ship operating time and fuel economy can be greatly increased and ship maintenance cost significantly reduced.

The objective of all UWSH operations is to provide a permanent repair which eliminates emergent drydocking and subsequent drydock rework costs. When a permanent repair is not possible, temporary repairs are performed. These temporary repairs allow the ship to operate until its next scheduled drydocking where permanent repairs can be accomplished.

It is essential that all UWSH repairs follow strict Quality Assurance (QA) and Quality Control (QC) procedures to ensure underwater systems are properly repaired. In undertaking UWSH repairs, divers must work closely with other repair activities to ensure procedures are in compliance with prescribed ship design and maintenance specifications. All relevant technical manuals must be available for dive planning, and individual diver's background and expertise must be considered when assembling dive teams. The NAVSEA *Underwater Ship Husbandry Manual* (S0600-AA-PRO-010) provides both general guidance and specific procedures to accomplish many underwater repairs.

Although many training requirements and qualifications are task specific, regular training may be accomplished by formalized instruction (as in First or Second Class Dive School), NAVSEA sponsored training (as in Sonar Dome Rubber Window (SDRW) Repair), On the Job Training (OJT), and Personnel Qualification Standards (PQS). However the training is accomplished, a successfully completed permanent repair will meet the same tolerances and QA/QC requirements as the same repair performed in drydock. If there are any questions as to the qualifications required for a permanent repair, divers should consult with their command repair department or contact NAVSEA 00C immediately (Comm. - (703) 607-2761 or DSN - 327-2761).

4-4.2 Salvage or Object Recovery. In a salvage or object recovery operation, divers work to recover sunken or wrecked naval craft, submersibles, downed aircraft, and other objects of interest. Recovering critical items of equipment can help determine the cause of a mishap. Divers can disassemble an object and raise the component parts or they can raise an entire object using various salvage techniques. Salvaged items may also include classified or sensitive materials, or other equipment.

4-4.3 Search Missions. Search swims are conducted to provide information, such as the location of underwater objects or subsurface geological formations. Searches can be performed by various methods depending on the undersea terrain and purpose of the mission. Because using divers for an unaided visual search over a large area is time consuming and labor intensive, search operations should incorporate the use of sidescan sonar and other electronic equipment whenever possible to aid in the search. Remotely Operated Vehicles (ROVs) may be used to extend searches into deep waters and areas that are particularly dangerous for a diver. A reconnaissance dive may be conducted prior to other scheduled dives to gather information which can save in-water time and identify any special hazards of the dive mission.

4-4.4 Security Swims. Security swims are employed to search for underwater explosives or other devices that may have been attached to ships or piers. If explosive devices are suspected, through-water communications should be considered in lieu of the use of a tending line. Ship security swims for ordnance may be conducted by non-EOD divers for purposes of location only. No attempt shall be made to handle or dispose of underwater ordnance or improvised explosive devices by non-EOD divers. Diving to render safe or dispose of explosive ordnance shall be accomplished by EOD divers only.

4-4.5 Explosive Ordnance Disposal. Divers who perform Explosive Ordnance Disposal (EOD) tasks work in a specialized field: the recovery, identification, disarming, and disposal of explosive devices that must be cleared from harbors, ships, and sea lanes. Once a task is identified which involves ordnance disposal, the area must be marked, EOD support requested, and all personnel warned to avoid contact with the ordnance.

4-4.6 Underwater Construction. Underwater construction is defined as the construction, inspection, repair, and removal of in-water facilities in support of military operations. An in-water facility can be defined as a fixed harbor, waterfront, or ocean structure located in or near the ocean. Examples include pipelines, cables, sensor systems, and fixed/advanced-base structures.

Seabee divers are specifically trained to employ special underwater techniques to accomplish these tasks. Formal training in underwater construction techniques is taught at the Basic and Advanced Underwater Construction Technician school in Port Hueneme, CA.

Tools and equipment used include common underwater tools in addition to specific, specialized ocean construction equipment. Specific tools and components for large ocean engineering projects are maintained in the Ocean Construction Equipment Inventory (OCEI) located at St Juilian Creek, Norfolk, VA.

References for underwater construction planning can be found in: *UCT Conventional Inspection and Repair Techniques Manual* NCEL TM-43-85-01, *Expedient Underwater Repair Techniques* NAVFAC P-991, and *Design and Installation of Nearshore Ocean Cable Protection Systems* FPO-1-78. For more information on ocean construction, commands should consult NAVFAC Ocean Facilities Program at (703) 325-0505, A/V 325-0505.

4-4.7 Demolition Missions. Diving personnel assigned to demolition duties are trained in the removal of man-made structures such as barriers, sunken naval craft, and damaged piers. These operations are conducted by blasting, freeing, flattening, or cutting with explosives. Divers may also be assigned to destroy natural formations, such as coral reefs, that interfere with transportation routes.

4-4.8 Combat Swimmer Missions. Combat swimmers are trained in the tasks of reconnaissance and neutralization of enemy ships, shore-based installations, and personnel. Some missions may require an underwater approach to reach coastal installations undetected. Reconnaissance missions and raids may expose the combat swimmers to additional risk but may be necessary to advance broader Naval objectives.

4-4.9 Enclosed Space Diving. Divers are routinely required to work in an enclosed or confined space. Using the Underwater Breathing Apparatus (UBA) MK 20 MOD 0, divers may enter submarine ballast tanks, mud tanks, sonar domes or cofferdams, which may be in either a flooded or dry condition. Access to these spaces is normally restrictive, making it difficult for the diver to enter and exit. Enclosed space diving is supported by a surface-supplied air system. Communication with the topside surface support personnel is provided by the MK 20 MOD 0.

4-4.9.1 Hazards. The interior of submarine ballast tanks, mud tanks, sonar domes, and cofferdams is hazardous due to limited access, poor visibility, and slippery surfaces. If an enclosed space is not flooded, it may contain a contaminated atmosphere.

4-4.9.2 Safety Precautions. The following precautions must be followed rigorously at all times in enclosed space operations.

- When a diver is working in an enclosed or confined space, the diver will be tended by another diver at the access opening.

- All divers will be outfitted with MK 20 MOD 0 which includes a diver-to-diver and diver-to-topside communications system, and an Emergency Gas Supply (EGS) for the diver inside the space.

- The divers shall not remove their diving equipment until the atmosphere has been flushed twice with air from a compressed air source meeting the requirements of Appendix L, or the submarine L.P. blower, and tests confirm that the atmosphere is safe for breathing. Tests of the air in the enclosed space must be conducted hourly. Testing shall be done in accordance with NSTM 074, Volume 3, Gas Free Engineering (S9086-CH-STM-030/CH-074). If the divers smell any unusual odors, they must immediatly don their masks.

- If the diving equipment should fail, the diver will immediately switch to the EGS and abort the dive.

4-5 COLLECT AND ANALYZE DATA

Information pertinent to the mission objective shall be collected, organized and analyzed to determine what may affect successful accomplishment of the objective. This process aids in:

- Planning for contingencies
- Developing the dive plan
- Selecting diving technique, equipment, and diver personnel
- Identifying potential hazards and any need for special emergency procedures.

4-5.1 Information Gathering. The extent and type of information that must be gathered are influenced by such factors as the size of the operation, the diving site location, and prevailing environmental conditions. Some operations are of a recurring nature, so that much of the required information may be readily available. An example of such an assignment is the removal of a propeller from a particular class of ship. However, even for a standard operation, the ship may have been modified or special environmental conditions may exist which would require a change in procedure or the use of special tools. Potential changes in task requirements affecting work procedures should not be overlooked during planning.

4-5.1.1 Planning Data. Many operations require the collection of detailed information in advance. For example, in planning for the salvage of a sunken or stranded vessel, the diving team needs to know the construction of the ship, the type and location of cargo, the type and location of fuel, the cause of the sinking or stranding, and the nature and degree of damage sustained. The sources of such information include ship's plans, cargo manifests and loading plans, interviews with witnesses and survivors, photographs, and official reports of similar accidents.

If the operation involves recovering an object from the bottom, the team needs to know the dimensions and weight of the object. Other useful information includes floodable volume, established lifting points, construction material, length of time on the bottom, probable degree of embedment in mud or silt, and the nature and extent of damage. This data helps define the type of lift to be used (e.g., boom, floating crane, lifting bags, pontoons), indicates whether high-pressure hoses are needed to jet away mud or silt, and helps determine the disposition of the object after it is brought to the surface. Preliminary operations planning may find the object too heavy to be placed on the deck of the support ship, indicating the need for a barge and heavy lifting equipment.

For any operation involving a search for an object or underwater site, data gathered in advance helps to limit the search area. This is of utmost importance because underwater searching by divers is time consuming and hazardous. For example, information useful in narrowing the search area for a lost aircraft includes: last known heading, altitude and speed; radar tracks plotted by ships and shore stations; tape recordings and radio transmissions; and eyewitness accounts.

Figure 4-2 is a list of planning data sources developed to assist supervisors in collecting data for locating and recovering an object. Much of the data gathered in the planning phase of an operation comes from outside sources or surface observations. This information is collected long before the actual diving phase begins. If time and conditions permit, preliminary dives by senior, experienced members of the team can be of great value in verifying, refining, and analyzing the data and in improving the dive plan.

4-5.1.2 Data Collection On Site. When a general area is outlined, use of side scan sonar with an X-Y plotter is helpful in locating the debris field, and an ROV can identify target items located by the side scan sonar. This method saves diver effort for the more critical phase of the search mission: recovering items of interest.

Whenever the object of a search has been found,

Planning Data Sources

Aircraft Drawings
Cargo Manifest
Coastal Pilot Publications
Cognizant Command
Communications Logs
Construction Drawings
Current Tables
Diving Advisory Messages
DRT Tracks
Electronic Analysis
Equipment Operating Procedures (OPs)
Equipment Operation & Maintenance Manuals
Flight Plan
Flight or Ship Records
Hydrographic Publications
Light Lists
Local Yachtsmen/Fishermen
LORAN Readings
Navigational Charts
Navigation Text (Duttons/Bowditch)
NAVOCEANO Data
Notices to Mariners
OPORDERS
Photographs
Radar Bearings
RDF Bearings
Salvage Computer Data
Sailing Directions
Ship's Curves of Forms
Ship's Drawings (including docking plan)
Ship's Equipment
Ship's Logs and Records
Ship's Personnel
SITREP
SINS Records
SONAR Readings and/or Charts
TACAN Readings
Tapes
Test Records
Technical Reference Books
Tide Tables
Underwater Work Techniques
USN Diving Manual Reference List
USN Ship Salvage Manual
USN Instructions
Visual Bearings
Weather Reports
Witnesses

Figure 4-2. Planning Data Sources.

the site should be marked, preferably with an acoustic transponder (pinger), or with a buoy.

Information must be collected as an aid in identifying hazards. For example, a diver working around a ship must know the location and status of ship sea suctions and discharge points, propellers, rudders, diving planes, and sonar transducers. If working on or near a vessel that has a nuclear propulsion system, the diver must be aware of radiological hazards, rules for working on or near such a vessel, and the locations of the reactor compartment, discharges, etc. Most importantly, the diver must be briefed on potential exposure and must wear proper underwater radiological exposure detection instruments.

For all diving operations, data involving the following general categories should be collected and analyzed.

- Surface conditions
- Underwater conditions
- Equipment and personnel resources
- Assistance in emergencies

4-5.2 Surface Conditions. Surface conditions in the operating area affect both the divers and the topside team members. These conditions are influenced by location, time of year, wind, waves, tides, current, cloud cover, temperature, visibility, and the presence of other ships. The Environmental Checklist, Figure 4-3, helps ensure that environmental factors are not overlooked during planning. For an extensive dive mission, a meterological detachment may be requested from the local/regional meterological support activity.

4-5.2.1 Natural Factors. Normal conditions for the area of operations can be determined from published tide and current tables, sailing

ENVIRONMENTAL CHECKLIST

Date __________

Surface

Atmosphere
Visibility ______________
Sunrise (set) ______________
Moonrise (set) ______________
Temperature (air) ______________
Humidity ______________
Barometer ______________
Precipitation ______________
Cloud Description ______________
Percent Cover ______________
Wind Direction ______________
Wind Force (knots) ______________
Other:
____
____
____

Sea Surface
Sea State ______________
Wave Action:
  Height ______________
  Length ______________
  Direction ______________
Current:
  Direction ______________
  Velocity ______________
  Type ______________
Surf. Visibility ______________
Surf. Water Temp. ______________
Local Characteristics:
____
____
____

Subsurface

Underwater & Bottom
Depth ______________
Water Temperature:
  ________ depth ________
  ________ depth ________
  ________ depth ________
  ________ bottom ________
Thermoclines ______________
____
Current:
  Direction ______________
  Source ______________
  Velocity ______________
  Pattern ______________
Tides:
  High Water ____/____ time
  Low Water ____/____ time
  Ebb Dir. ________ Vel. ________
  Flood Dir. ________ Vel. ________

Visibility
Underwater
  ft ________ at ________ depth
  ft ________ at ________ depth
  ft ________ at ________ depth
Bottom
  ft ________ at ________ depth
Bottom Type:
____
Obstructions:
____
____
____
Marine Life:
____
____
____
Other Data:
____
____

NOTE: A meteorological detachment may be requested from the local meteorological support activity.

Figure 4-3. Environmental Checklist. This environmental checklist is a sample worksheet indicating categories of data that might be gathered for an operation. Each planner should develop a similar checklist to suit the particular situation. The data collected is vital for effective operations planning. This data is also of particular value when filing Post Salvage Reports.

directions, notices to mariners, and special charts that show seasonal variations in temperature, wind, and ocean currents. Weather reports and long-range weather forecasts must be studied to determine if conditions will be acceptable for diving. Weather reports must be continually monitored while an operation is in progress.

NOTE

> A recommendation that diving be discontinued shall be made to the CO or OIC if conditions, in the opinion of the Diving Officer, Master Diver, or Diving Supervisor, place the diver at unnecessary risk.

A significant factor is the sea state (Figure 4-4). Wave action can affect everything from the stability of the moor to the vulnerability of the crew to seasickness or injury. Unless properly moored, a ship or boat drifts or swings around an anchor, fouling lines and dragging divers. Because of this, any vessel being used to support surface-supplied or tended diving operations must be secured by at least a two-point moor. A four-point moor, while more difficult to set, is preferred. Exceptions occur when moored alongside a pier or another vessel that is properly anchored, or when a ship is performing diving during open ocean transits and can not moor due to depth.

Divers are not particularly affected by the action of surface waves unless operating in surf, in shallow waters, or if the waves are exceptionally large. Below a depth which varies with the surface conditions, a diver will be unaware of any wave action. Surface waves may become a problem when the diver enters or leaves the water, and during decompression stops near the surface.

Effective dive planning must provide for extreme temperatures that may be encountered on the surface. Normally, such conditions are a greater problem for tending personnel than for a diver. Any reduction in the effectiveness of the surface crew may endanger the safety of a diver. The particular problems that must be guarded against are:

- Sunburn
- Windburn
- Hypothermia
- Frostbite
- Heat Exhaustion

In cold, windy weather, the wind chill factor must also be considered. Exposure to cold winds greatly increases dangers of hypothermia and all types of cold injury. For example, if the actual temperature is 35°F and the wind velocity is 35 mph, the wind-chill factor is equivalent to 5°F (Figure 4-5). For additional information see Appendix J.

Variations in surface visibility are important. Reduced visibility may seriously hinder or force postponement of diving operations. For operations to be conducted in a known fog belt, the diving schedule should allow for probable delays because of low visibility. Diver and support crew safety is the prime consideration when determining whether surface visibility is adequate. For example, a surfacing diver might not be able to find his support craft, or the diver and the craft itself might be in danger of being hit by surface traffic. A proper radar reflector for small craft should be considered.

NOTE

> Diving shall be discontinued if sudden squalls, electric storms, heavy seas, unusual tide, or any other condition exists that, in the opinion of the Diving Super-

SEA STATE CHART

Sea State	Description	Wind Force (Beaufort)	Wind Description	Wind Range (knots)	Wind Velocity (knots)	Average Wave Height (ft)
0	Sea like a mirror.	0	Calm	<1	0	0
	Ripples with the appearance of scales are formed, but without foam crests.	1	Light Air	1-3	2	0.05
1	Small wavelets, still short but more pronounced; crests have a glassy appearance but do not break.	2	Light Breeze	4-6	5	0.18
2	Large wavelets, crests begin to break. Foam of glassy appearance, perhaps scattered whitecaps.	3	Gentle Breeze	7-10	8.5 10	0.6 0.88
3	Small waves, becoming longer; fairly frequent whitecaps.	4	Moderate Breeze	11-16	12 13.5 14 16	1.4 1.8 2.0 2.9
4	Moderate waves, taking a more pronounced long form; many whitecaps are formed. Chance of some spray.	5	Fresh Breeze	17-21	18 19 20	3.8 4.3 5.0
5	Large waves begin to form; white foam crests are more extensive everywhere. Some spray.	6	Strong Breeze	22-27	22 24 24.5 26	6.4 7.9 8.2 9.6
6	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. Spindrift begins.	7	Moderate Gale	28-33	28 30 30.5 32	11 14 14 16
7	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh Gale	34-40	34 36 37 38 40	19 21 23 25 28
8	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong Gale	41-47	42 44 46	31 36 40
9	Very high waves with long overhanging crests. Foam is in great patches and is blown in dense white streaks along the direction of the wind. The surface of the sea takes on a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility is affected.	10	Whole Gale	48-55	48 50 51.5 52 54	44 49 52 54 59
	Exceptionally high waves. The sea is completely covered with long white patches of foam along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility seriously affected.	11	Storm	56-63	56 59.5	64 73
	Air filled with foam and spray. Sea completely white with driving spray. Visibility very seriously affected.	12	Hurricane	64-71	>64	>80

Figure 4-4. Sea State Chart.

TEMPERATURE

Degrees Fahrenheit (Degrees Celsius)

Wind MPH	Actual Air Temperature						
	40(4)	35(2)	30(-1)	25(-4)	20(-7)	15(-9)	10(-12)
	Equivalent Chill Temperature °F (°C)						
5	35(2)	30(-1)	25(-4)	20(-7)	15(-9)	10(-12)	5(-15)
10	30(-1)	20(-7)	15(-9)	10(-12)	5(-15)	0(-17)	-10(-23)
15	25(-4)	15(-9)	10(-12)	0(-17)	-5(-21)	-10(-23)	-20(-29)
20	20(-7)	10(-12)	5(-15)	0(-17)	-10(-23)	-15(-26)	-25(-32)
25	15(-9)	10(-12)	0(-17)	-5(-21)	-15(-26)	-20(-29)	-30(-34)
30	10(-12)	5(-15)	0(-17)	-10(-23)	-20(-29)	-25(-32)	-30(-34)
35	10(-12)	5(-15)	-5(-21)	-10(-23)	-20(-29)	-30(-34)	-35(-37)
40	10(-12)	0(-17)	-5(-21)	-15(-26)	-20(-29)	-30(-34)	-35(-37)
	5(-15)	0(-17)	-5(-21)	-10(-23)	-15(-26)	-20(-29)	-25(-32)
	Equivalent Chill Temperature °F (°C)						
5	0(-17)	-5(-15)	-10(-23)	-15(-26)	-20(-29)	-25(-32)	-30(-34)
10	-15(-26)	-20(-24)	-25(-32)	-35(-37)	-40(-40)	-45(-43)	-50(-46)
15	-25(-32)	-30(-34)	-40(-40)	-45(-43)	-50(-46)	-60(-51)	-65(-45)
20	-30(-34)	-35(-37)	-45(-43)	-50(-46)	-60(-51)	-65(-54)	-75(-60)
25	-35(-37)	-45(-43)	-50(-46)	-60(-51)	-65(-54)	-75(-60)	-80(-62)
30	-40(-40)	-50(-46)	-55(-48)	-65(-54)	-70(-57)	-80(-62)	-85(-65)
35	-40(-40)	-50(-46)	-60(-51)	-65(-54)	-75(-60)	-80(-62)	-90(-68)
40	-45(-43)	-55(-48)	-60(-51)	-70(-57)	-75(-60)	-85(-65)	-95(-71)
	-30(-34)	-35(-37)	-40(-40)	-45(-43)	-50(-46)	-55(-48)	-60(-51)
	Equivalent Chill Temperature °F (°C)						
5	-35(-37)	-40(-40)	-45(-43)	-50(-46)	-55(-48)	-60(-51)	-70(-57)
10	-60(-51)	-65(-54)	-70(-57)	-75(-60)	-80(-62)	-90(-68)	-95(-71)
15	-70(-57)	-80(-62)	-85(-65)	-90(-68)	-100(-73)	-105(-76)	-110(-79)
20	-80(-62)	-85(-65)	-95(-71)	-100(-73)	-110(-79)	-115(-82)	-120(-85)
25	-90(-68)	-95(-71)	-105(-76)	-110(-79)	-120(-85)	-125(-87)	-135(-93)
30	-95(-71)	-100(-73)	-110(-79)	-115(-82)	-125(-87)	-130(-90)	-140(-96)
35	-100(-73)	-105(-76)	-115(-82)	-120(-85)	-130(-90)	-135(-93)	-145(-98)
40	-100(-73)	-110(-79)	-115(-82)	-125(-87)	-130(-90)	-140(-96)	-150(-101)

Winds above 40 MPH have little additional effect

- LITTLE DANGER
- INCREASING DANGER (flesh may freeze within one minute)
- GREAT DANGER (flesh may freeze within 20 seconds)

Figure 4-5. Equivalent Wind Chill Temperature Chart.

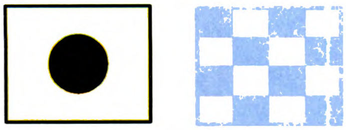
visor, jeopardizes the safety of the divers.

4-5.2.2 Vessel Traffic and Other Factors. Because many diving operations are conducted in harbors, rivers, and major shipping channels, the presence of other ships is often a serious problem. It may be necessary to close off an area or limit the movement of other ships. A local Notice to Mariners should be issued. At any time that diving operations are to be conducted in the vicinity of other ships, they should be properly notified by International Code signal flags (Figure 4-6). An operation may have to be conducted in an area with many small boats operated by people with varied levels of seamanship and knowledge of Nautical Rules of the Road. The diving team should assume that these operators are not acquainted with the meaning of diving signals and take the necessary precautions to ensure that these vessels remain clear of the diving area. When small civilian boats are in the area, use the civilian Sport Diver flag (red with white diagonal stripe) as well as "Code Alpha". Hazards associated with vessel traffic are intensified under conditions of reduced visibility.

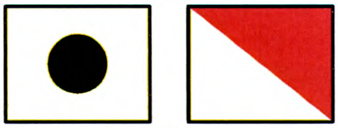
Other factors of location and surface conditions that may influence diving operations are territorial claims by other nations, the presence of foreign intelligence collection ships, and the potential for hostile action.

4-5.3 Underwater Environmental Conditions. Underwater environmental conditions have a major influence on the selection of divers, diving technique, and the equipment to be used. Conditions having some effect on all diving operations are:

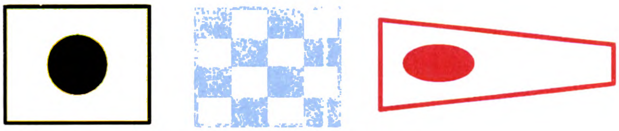
- **Depth -** Depth is a major factor in selecting both diving personnel and apparatus, and influences the decompression profile for any dive. Operations in deep waters may also call for the use of special support



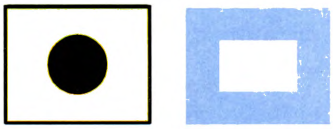
IN: "I require a diver."



IO: "I have no diver."



IN1: "I require a diver to clear my propeller."

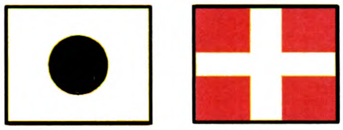


IP: "A diver will be sent as soon as possible (or at time indicated)."

IN2: "I require a diver to examine bottom."

IQ: "Diver has been attacked by diver's disease and requires decompression chamber treatment."

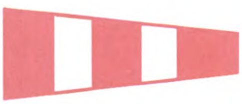
IN3: "I require a diver to place collision mat."



IR: "I am engaged in submarine survey work (underwater operations). Keep clear of me and go slow."

IN4: "I require a diver to clear my anchor."

A: "I have a diver down; Keep well clear at slow speed." (Note 2)



Code Flag (Note 1)

Sport Diver (Unofficial)

General Note: Rule 27 of Navigation Rules-International-Inland of December 1983 states the lights and shapes that must be displayed when engaged in diving operations.

Note 1: International Signal Code -- All signals must be preceded by the code flag to signify that they are international signals. (Do not use code flag in inland waters.)

Note 2: The alpha flag should be of rigid construction.

Figure 4-6. International Code Signal Flags.

equipment (i.e., underwater lights, cameras, ROV, etc.).

Depth must be carefully measured to ensure accuracy. Depth measurements must be plotted over the general area of the operation to get an accurate depth profile of the dive site. Soundings by a ship-mounted fathometer are reasonably accurate but must be verified by either a lead line sounding, a pneumofathometer (Figure 4-7), or a high resolution sonar (bottom finder or fish finder). Depth readings taken from a chart are to be used only as an indication of probable depth.

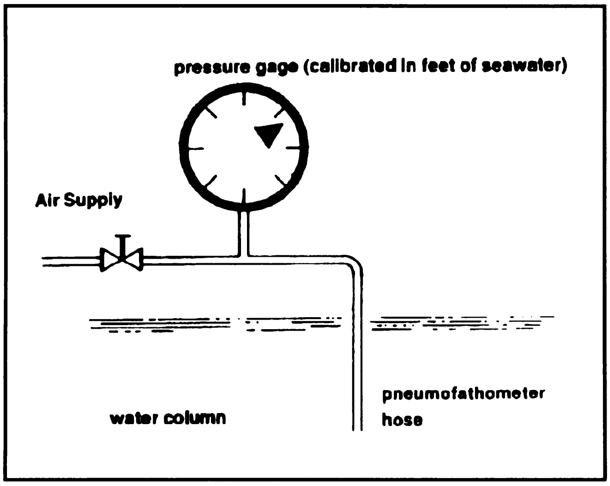


Figure 4-7. Pneumofathometer. The pneumofathometer hose is attached to a diver or weighted object and lowered to the depth to be measured. Water is forced out of the hose by pressurized air until a generally constant reading is noted on the pressure gauge. The air supply is secured, and the actual depth (equal to the height of the water column displaced by the air) is read on the gauge.

Pneumofathometer hose may be any flexible non-metallic, air or water service hose with 1/4-inch min I.D., and 700 psig min burst pressure. Fitting shall be brass female oxygen union nut and nipple compatible with hose design. Pneumofathometer hose may remain in service until failure to pass PMS requirements.

- **Type of bottom -** The type of bottom may have a significant effect upon a diver's ability to move and work efficiently and safely. Advance knowledge of bottom conditions is important in scheduling work, selecting dive technique and equipment, and anticipating possible hazards. The type of bottom is often noted on the chart for the area, but conditions can change within just a few feet. Independent verification of the type of bottom should be obtained by sample or observation. Figure 4-8 outlines the basic types of bottoms and the characteristics of each.

- **Tides and currents -** The basic types of currents that affect diving operations are:

  - River or major ocean currents
  - Current produced by the ebb and flow of the tides (which may add to or subtract from any existing current)
  - Undertow or rip current, caused by the rush of water returning to the sea from waves breaking along a shoreline
  - Surface current generated by wind

The direction and velocity of normal river, ocean, and tidal currents will vary with time of the year, phase of the tide, configuration of the bottom, depth of water, and weather. Tide and current tables show the conditions at the surface only and should be used with caution when planning diving operations. The direction and velocity of the current beneath the surface may be quite different. Usually there is much less current on the bottom than at the surface. Consequently, although the surface tidal current may be strong, bottom conditions may be well within the permissible range for diving.

Rip currents will vary with the weather, the state of the tide, and the slope of the bottom. These currents may run as fast as two knots and may extend as far as one-half mile from shore. Rip currents, not usually identified in published ta-

Bottom Conditions and Effects Chart

Type	Characteristics	Visibility	Diver Mobility On Bottom
Rock	Smooth or jagged, minimum sediment	Generally unrestricted by diver movement	Good, excercise care to prevent line snagging and falls from ledges.
Coral	Solid, sharp and jagged, found in tropical waters only	Generally unrestricted by diver movement	As above
Gravel	Relatively smoooth, granular base	Generally unrestricted by diver movement	Good, occasional sloping bottoms of loose gravel impair walking and cause instability.
Shell	Composed principally of broken shells mixed with sand or mud	Shell-sand mix does not impair visibility when moving over bottom. Shell-mud mix does impair visibility. With higher mud concentrations, visibility is increasingly impaired.	Shell-sand mix provides good stability. High mud content can cause sinking and impaired movement.
Sand	Common type of bottom, packs hard	Generally unrestricted by diver movement	Good
Mud and Silt	Common type of bottom, composed of varying amounts of silt and clay, commonly encountered in river and harbor areas	Poor to zero. Work into the current to carry silt away from job site, minimize bottom disturbance. Increased hazard presented by unseen wreckage, pilings, and other obstacles.	Poor, can readily cause diver entrapment. Crawling may be required to prevent excessive penetration, fatiguing to diver.

Figure 4-8. Bottom Conditions and Effects Chart.

bles, can vary significantly from day to day in force and location.

Wind-generated surface currents are temporary and depend on the force, duration, and fetch of the wind. If the wind has been blowing steadily for some time, this current should be taken into consideration when planning surface swims and SCUBA dives.

A diver wearing a surface-supplied outfit, i.e., MK 12 SSDS with a lifeline and heavy weights, can usually work in currents up to 1.5 knots without undue difficulty. If supplied with an additional weighted belt, the diver may be able to accomplish useful work in currents as strong as 2.5 knots. A SCUBA diver is severely handicapped by currents greater than 1.0 knot. If planning an operation in an area of strong current, it may be necessary to schedule work during periods of slack water to minimize the tidal effect.

- **Visibility** - Underwater visibility varies with depth and turbidity. Horizontal visibility is usually quite good in tropical waters; a diver may be able to see more than 100 feet at a depth of 180 feet. Vertical visibility is almost always less than horizontal visibility. Visibility is poorest in harbor areas because of river silt, sewage, and industrial wastes flowing into the harbor. Agitation of the bottom caused by strong currents and the passage of large ships is also a factor.

The degree of underwater visibility influences selection of dive technique, and can greatly increase the time required for a diver to complete a given task. For example, a diving team preparing for harbor operations should plan for extremely limited visibility, possibly resulting in an increase in bottom time, a longer period on station for the diving unit, and a need for additional divers on the team.

- **Temperature** - Figure 4-9 illustrates the degree to which water temperature can affect a diver's performance and is intended as a guide for planning. A diver's physical condition, amount of body fat, and thermal protection equipment determines how long exposure to extreme temperatures can be endured safely. In cold water, ability to concentrate and work efficiency will decrease rapidly. Even in water of moderate temperature (60°F - 70°F, 15.5°C - 21.5°C), body heat loss to the water can quickly bring on diver exhaustion.

Other conditions such as the presence of ice, hazardous contaminants, altitude, and other obstacles or hazards require special consideration and affect only some dives. These topics are discussed in Paragraphs 4-5.4 through 4-5.7.

4-5.4 Ice/Cold Water Diving. Ice/cold water conditions affect diving operations but do not prevent them when proper equipment and operational techniques are used. The success of such an operation depends upon effective planning and preparation, and the ability of each team member to adjust to and work in this adverse environment.

Divers operating in arctic or subarctic environments must be specially trained for cold water and ice diving. Thermal protection must be provided for all personnel at the dive station to ensure that all members of the diving team are able to perform their tasks while exposed to the extreme cold. Careful planning of the mission, and coordination of logistics and evacuation are essential due to the hazards presented in the harsh environment.

The following considerations are critical to the success of diving operations in polar areas or in ice-covered, near-freezing waters in non-polar regions. Appendix J of this manual, Ice/Cold Water Diving Operations, and the *Polar Operations Manual*, NAVSEA S0300-85-MAN-010, provide more detailed information and should be referred to prior to any diving operation in such areas. Chapter 3 and Chapter 8 of this manual should also be referred to for guidance concerning body heat loss and hypothermia.

- **Logistics** - Careful planning is mandatory to successfully transport a diving operation with complete supplies and equipment to very cold regions. In no other place on earth is the success or failure of a diving operation so closely tied to dependable logistic support.

- **Support Equipment** - The support equipment required for ice and cold water diving must be carefully evaluated for effectiveness and suitability. All cold weather maintenance for a particular

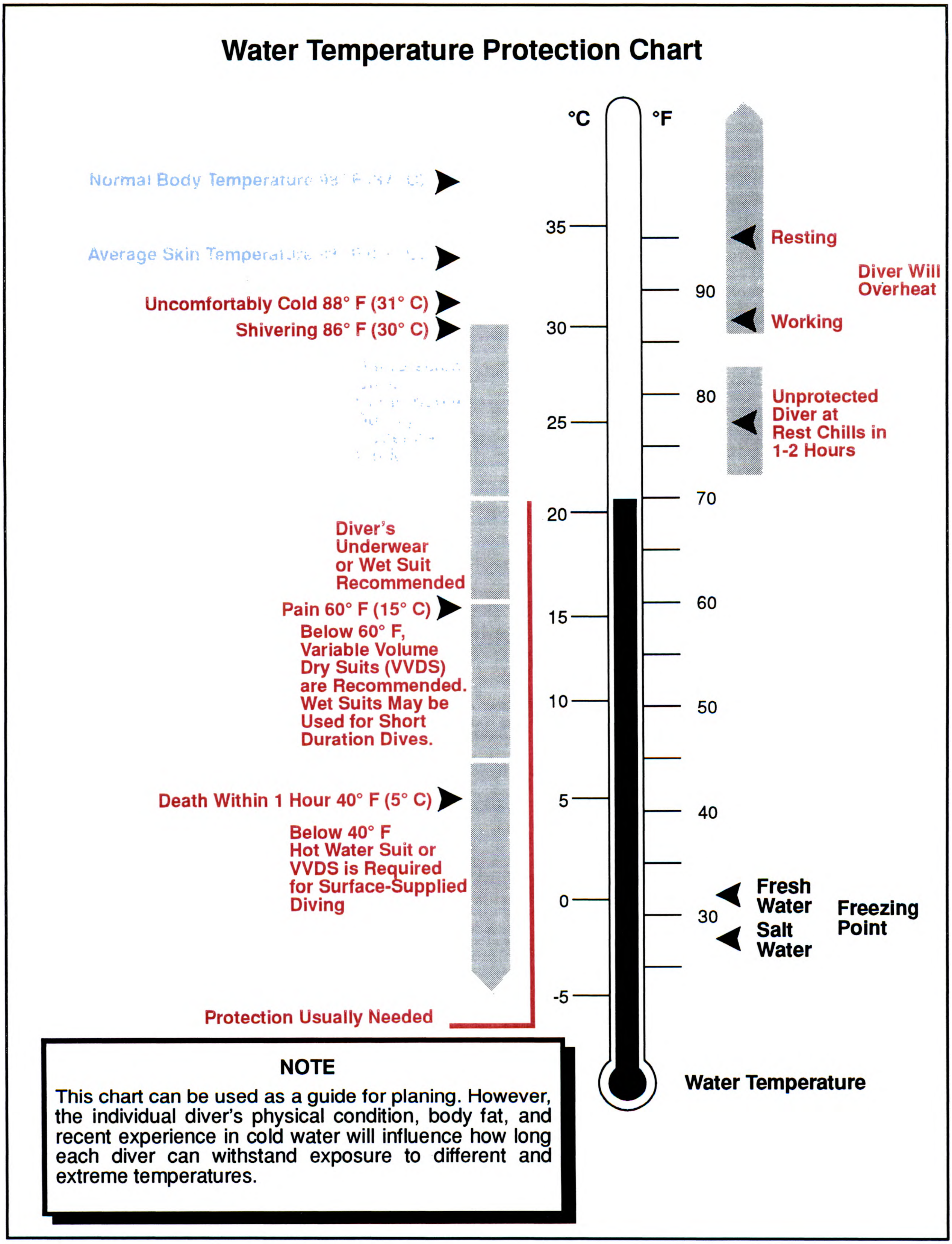


Figure 4-9. Water Temperature Protection Chart.

piece of equipment must be accomplished with extreme care (see Appendix J).

- **Shelters** - Most ice and cold water diving operations require some type of surface shelter to protect personnel and equipment. Depending on the nature of the mission and location of the site, shelters can range from small tents to large insulated huts.

- **Diver Thermal Protection** - The variable volume dry suit and hot water suit are effective means of thermal protection for cold water diving. Wet suits made of incompressible material are now available. Such suits offer more protection at depth than standard wet suits of the same thickness. However, in shallow water (less than 20 feet) where the compression of the standard suit's neoprene material is negligible, the incompressible suit has no advantage.

- **Regulators** - Both single- and double-hose regulators are used for ice and cold water diving. The single-hose regulator is preferred for buddy breathing, is less bulky, and is easier to maintain than the double-hose; however, it is more subject to freeze-up than the double-hose regulator. Due to the serious nature of the freeze-up problems in single-hose regulators, they should not be allowed to free-flow or be purged for over five seconds at a time. Only authorized regulators having a cold water conversion kit listed in NAVSEA Instruction 10560.2 (series) shall be used for ice/cold water diving. Further restrictions are identified in Appendix J.

- **Weight Belts** - More weight must be used with a variable volume dry suit than with a wet suit due to the great positive buoyancy of a dry suit. Manufacturer's recommendations should be followed to select starting weight. The additional weight makes use of a weight vest or harness desirable. A shoulder harness is one method of preventing the heavy, awkward belts from slipping down during a dive. A few heavy hip hugger weights are better than several smaller weights.

- **Stage** - A small stage or platform hanging below the surface at an ice entry hole is helpful for missions requiring the use of support equipment such as cameras, tools, or lights. Its use reduces the number of times the equipment must be transferred into and out of the water, and lessens problems and possible damage from temperature changes.

- **Tending Line** - For under-ice diving, a tending line or lifeline is mandatory and serves as a means of communication between diver and surface, as a guide back to the entrance, and as a means of recovering an injured diver. The line should be neutrally buoyant with one end affixed to the diver, not to the equipment. A synthetic line that will not freeze when pulled out of the water is required; manila or hemp rope is not authorized.

- **Life Preservers** - For under-ice diving only, a life preserver is not required as it would pose a hazard to the diver. If accidently inflated, the life preserver would cause the diver to impact under the ice, and the life preserver impedes access to the dry suit dump valve.

- **Air Compressors** - Air compressors should be placed in a dry, heated shelter with the intake line extended to the outside atmosphere. Particular attention should be paid to the oil/moisture separator to prevent freeze-up.

- **Diver Transport** - Occasionally one site will double as both the dressing area and the diving area, such as ship-supported and remote-site operations, eliminating any requirements for diver transport. Usually, however, the divers must be transported from the dressing area to the diving site. How this is accomplished will depend on distance, weather, site accessibility, and vehicle availability. The primary objective is to transport the divers as quickly as possible with a minimum of exposure.

- **Dive Platform -** Diving operations in cold regions may be conducted from a variety of support platforms including: open beach, small craft, ships, ice floes, ice islands, lockout submersibles, and solid ice covers such as fast or pack ice. Often, a suitable entry hole must be cut in the ice for divers and support equipment.

- **Navigation -** Underwater navigation in cold and ice-covered waters is difficult and requires special equipment and procedures (see Appendix J).

Several techniques have been used for under-ice navigation with varying degrees of success. These include use of a tether, acoustic beacon strobe light, and clearing snow trails on the surface of the ice.

- **Buddy Breathing -** All divers should practice buddy breathing in polar waters before they make any excursions away from the entry hole. For water temperatures below 37°F, use of dual manifolds as well as ANU regulators is required (Appendix J).

- **Personnel Considerations -** An individual thoroughly conditioned physically can be transported from warm climates into cold climates and immediately begin diving without harmful effects. However, individuals differ in how well suited they are for cold weather operations. At least half of the diving team should have previous experience in ice or cold water diving operations and should be well qualified to train the less experienced.

- **Prevention of Cold Injury -** Personnel scheduled to go to polar regions should be instructed in cold weather physiology and the prevention of cold injuries. To prevent injury, any techniques which aid heat balance, protection, and basic metabolism should be used. The health of divers and their confidence in meeting the rigors of cold water diving are related directly to physical condition. The effect of physical fitness on morale cannot be overemphasized. It is important to keep warm, eat properly, and keep dry when not diving.

4-5.5 Contaminated Water Diving. When planning for contaminated water diving, medical personnel should be consulted to ensure proper predive precautions are taken and post-dive monitoring of divers is conducted. Other resources outside the scope of this manual may be required to deal with some nuclear, biological, or chemical contaminants. Appropriate resources and technical advice for dealing with contaminated water diving conditions may be available from the National Oceanic and Atmospheric Administration (NOAA) (HAZMAT Dept (206) 526-6317, Fax - (206) 526-6329).

4-5.5.1 Thermal Pollution. Divers may encounter dangerous or unpleasant forms of pollution that can cause severe problems. Occasionally a diver may be called upon to work in the vicinity of a sewer or industrial outfall discharging high temperature wastes. In such situations, the diver must be particularly alert for the symptoms of exhaustion. To date, no practical diving apparatus or dress has been designed to protect the diver against unusually warm water although hot water suits may be used with cold water piped to the diver. A diver working near sewer outlets or industrial discharges may also be exposed to the hazards of disease or chemical poisoning.

4-5.5.2 Chemical/Radiological Contamination. Oil leaking from underwater wellheads or damaged fuel tanks can cause fouling of equipment and seriously impede a diver's movements. Toxic materials or volatile fuels leaking from barges or tanks can irritate the skin and corrode equipment. Most work in chemically contaminated waters will be performed while on the bottom and will involve the recovery or disposal of chemical ordnance or hazardous chemical containers. The dive unit should not conduct the dive until the contaminant has been identified, the safety factors evaluated, and the process for decontamination set up. When working in a radiological environment, proper radiological procedures must be followed.

Divers operating in waters where a chemical or chemical warfare threat is known or suspected must evaluate the threat and protect themselves as appropriate. The MK 12 SSDS dry suit dress assembly, affords limited protection. A Chemical Warfare Protective Dive Suit is under development by the Navy. The suit is a chemically resistant, leak-free dry suit with integral gloves.

4-5.5.3 Biological Contamination. SCUBA divers are especially vulnerable to ear and skin infections when diving in waters that contain biological contamination. Divers may also inadvertently take polluting materials into the mouth, posing both physiological and psychological problems. In planning for operations in waters known to be polluted, protective clothing and appropriate preventative medical procedures must be provided. It is highly recommended that diving equipment be selected that will give the diver maximum facial protection. External ear prophylaxis should be provided to diving personnel to prevent ear infections. The Diving Supervisor should observe and time ear prophylaxis when diving in water where external otitis is known to be a problem (see Chapter 8).

4-5.6 Altitude Diving. Divers may be called upon to perform tasks in bodies of water at higher altitudes. Planning must address the effects of the atmospheric pressures that may be much lower than those at sea level. U.S. Navy Standard Decompression Tables are designed for use only at altitudes below 2,300 feet above sea level. Transportation of divers out of the diving area, which may include movement into even higher elevations either overland or by plane, requires special consideration and planning. The Diving Supervisor must be particularly alert for symptoms of hypoxia and decompression sickness after the dive due to the lower oxygen partial pressure and atmospheric pressure. NAVSEA 00C must be consulted and approval given prior to execution of any altitude diving operation to be conducted more than 2300 feet above sea level. Appropriate decompression tables and guidance will be provided by NAVSEA 00C to support altitude diving.

4-5.7 Operational Hazards. In addition to environmental hazards, and those directly attributable to diving, a diver may occasionally be exposed to operational hazards that are not unique to the diving environment.

Operational hazards include:

- **Underwater Obstacles -** Various underwater obstacles (e.g., wrecks or discarded munitions) offer serious hazards to diving. Wrecks and dumping grounds are often noted on charts, but the actual presence of such obstacles might not be discovered until an operation begins. This is one of several reasons for scheduling a reconnaissance dive or preliminary inspection dive before a final work schedule or detailed dive plan is prepared.

- **Electrical Shock -** Electrical shock is rare underwater but may occur when using electric welding or power equipment. All such equipment should be in good repair, and be inspected before diving. A Ground Fault Interrupter (GFI) must be used with underwater electrical equipment. Correct operating procedures and safety rules should always be observed. Ship cathodic protection devices must be secured while divers are operating in the vicinity.

- **Explosions -** Explosions may be set off in demolition tasks intentionally, accidentally, or as the result of enemy action. When working with or near explosives, the procedures given in NAVSEA Publications OP2081 and SWO 60-AA-MMA-010 must be followed. Divers should stay clear of old or damaged munitions. Divers should get out of the water when an explosion is imminent. Welding or cutting torches may cause an explosion on penetration of gas-filled compartments.

- **Sonar -** Low frequency sonar is used by ships for object location and depth finding. It is a dense, high-energy pulse of sound that can cause damage to divers' ears. Avoid diving in the vicinity of low frequency sonar, approach no closer than 600 yards, but optimum distance is 3,000 yards. If it is necessary to work closer than this, the Diving Supervisor should plan his dive in accordance with information provided in NAVSEA Instruction 3150.2 (series). High frequency (greater than 100kHz), short duration sonar, such as used with high resolution sidescan sonar, poses little danger to the diver.

- **Nuclear Radiation -** Radiation may be encountered as the result of an accident, proximity to weapons or propulsion systems, weapons testing, or occasionally, natural conditions. Exposure to radiation can cause serious injury and illness. Levels of safe tolerance have been set and must not be exceeded. These levels may be found in the *Radiological Control Manual*, NAVSEA 0389-LP-015-3000. Prior to diving, all dive team members must be thoroughly knowledgeable of the hazards involved. All divers must have a thermal luminescence dosimeter (TLD) or similar device and be apprised of the locations of items such as the reactor compartment, discharges, etc. The Radiological Control Officer of the vessel being worked on must be consulted.

- **Marine Life -** Certain marine life, because of its aggressive or venomous nature, may be dangerous to man. Some species of marine life are extremely dangerous; some are merely an uncomfortable annoyance. Most dangers from marine life are largely overrated because most underwater animals leave man alone. The diver's best protection against injury is knowledge. All divers should be able to identify the dangerous species which are likely to be found in the area of operation, and should know how to deal with each. Avoidance is the diver's best defense. Appendix G presents specific information about dangerous marine life, including identification factors, dangerous characteristics, injury prevention, and methods of treatment.

- **Flying After Diving -** Divers should not fly for 12 hours after surfacing from a decompression dive or for two hours following a no-decompression dive. If aircraft cabin pressure is below 2,300 feet altitude, then flying may be done immediately after any air dive.

4-5.8 Resources. Often, the manner in which an operation is planned and conducted will depend upon variables not under the control of the diving team. In some operations a mission-related time factor takes precedence over other considerations, while in other operations the availability of equipment or personnel will be a controlling factor. For any operation, the planning effort must identify available resources, which include time, personnel, equipment, support or auxiliary equipment, and supplies in order to:

- Ensure the safety of all personnel
- Identify shortages or inadequacies which should be remedied
- Permit accomplishment of the operational objectives in a timely and effective manner

4-6 SELECT DIVING TECHNIQUE

There are four basic types of air diving equipment in current use for U.S. Navy diving operations (Figure 4-10):

- Open-circuit SCUBA
- Surface-supplied lightweight gear (MK 21 MOD 1)
- MK 20 MOD 0
- Surface-supplied deep-sea gear (MK 12)

Other diving techniques such as oxygen, mixed-gas, and saturation diving are discussed in Volume 2 of this manual.

In some operations there may be no clear-cut choice. The selection of diving technique may depend upon availability of equipment or trained personnel.

The general characteristics of each type of diving are described in Paragraph 4-12. The following comparison of SCUBA and surface-

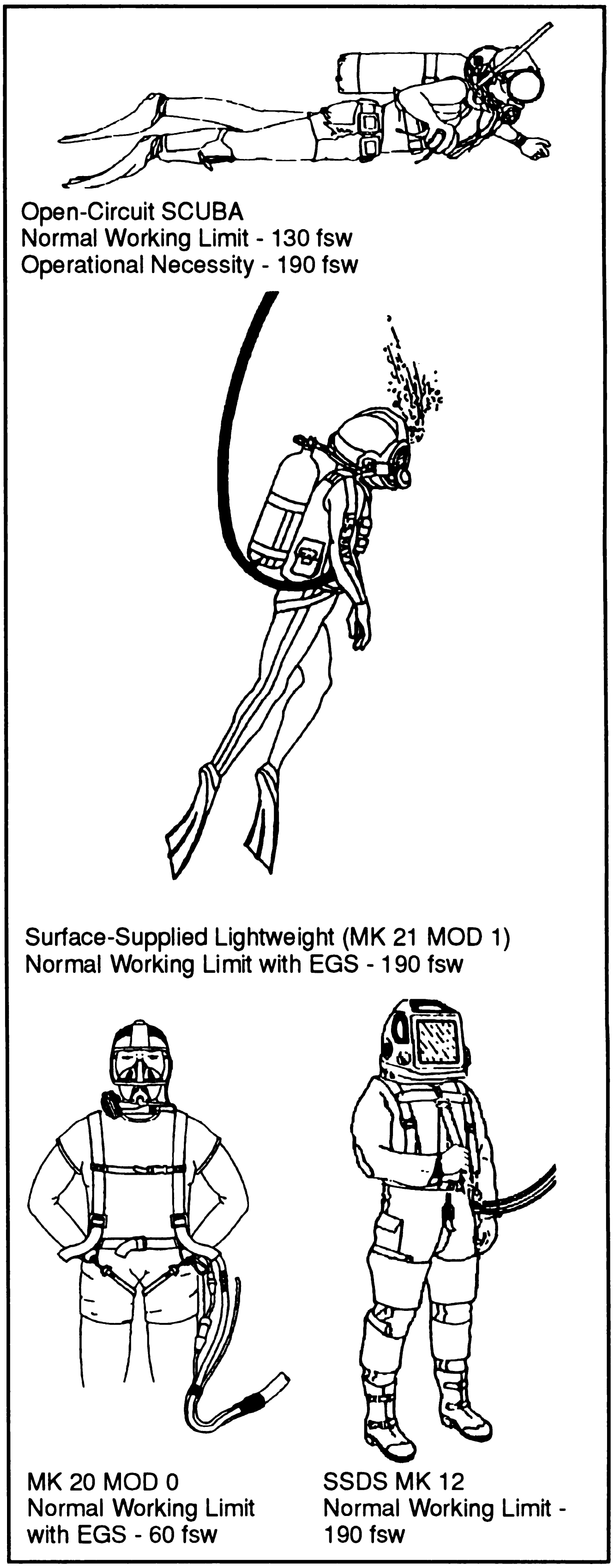


Figure 4-10. Air Diving Techniques. A choice of four air diving techniques are available: open-circuit SCUBA, surface-supplied lightweight gear, MK 20 MOD 0 and surface-supplied deep-sea gear.

supplied techniques highlights the significant differences between the methods, and outlines the effect these differences will have on planning.

4-6.1 Comparison of SCUBA and Surface-Supplied Diving. In this volume, the term SCUBA refers to open-circuit air SCUBA unless otherwise noted. A close look at the advantages and disadvantages of SCUBA will emphasize best the basic factors by which it may be compared to surface-supplied gear.

4-6.1.1 Operational Characteristics of SCUBA. The main advantages of SCUBA are mobility, depth flexibility and control, portability, and reduced requirement for surface support. The main disadvantages are limited depth, limited duration, lack of voice communications (unless equipped with a through-water communications system), limited environmental protection, remoteness from surface assistance, and the negative psychological and physiological problems associated with isolation and direct exposure to the underwater environment.

The SCUBA diver is not hindered by bulky or heavy equipment and can cover a considerable distance, with an even greater range through the use of diver propulsion vehicles (DPVs), moving freely in any direction. However, the SCUBA diver must be able to ascend directly to the surface in case of emergency. If direct ascent is not possible, then the diver must be tethered to the surface and tended.

NOTE

SCUBA equipment is not authorized for use in enclosed-space diving.

SCUBA equipment is designed to have nearly neutral buoyancy when in use, permitting the diver to change or maintain depth with ease. This gives the SCUBA diver the advantage of being able to work at any level in the water column. A surface-supplied diver using deep-sea gear will need rigging or staging.

The portability and ease with which SCUBA can be employed are distinct advantages. SCUBA equipment can be transported easily and put into operation with minimum delay. SCUBA offers a flexible and economical method for accomplishing a range of tasks within its operational limitations (i.e., search, light work).

Operational limitations as described in Paragraph 4-6.3 must be considered. Also, the SCUBA diver must remain within the limits of the No-Decompression Table (Chapter 7) except in an emergency. Bottom time is limited by the SCUBA's fixed air supply which is depleted more rapidly when diving deep or working hard.

The SCUBA diver is not as well protected from cold or from contact with marine plants and animals as a diver in surface-supplied gear, and is more easily swept along by current. Even when accompanied by a dive partner, the SCUBA diver usually swims in isolation, without surface contact or communications; however, increased use of through-water communications devices may alleviate this situation.

4-6.1.2 Operational Characteristics of SSDS. Surface-supplied diving systems can be divided into two major categories: lightweight and deep-sea. Surface-supplied lightweight gear allows the diver almost as much mobility as SCUBA and offers greater thermal protection when used with a hot water suit. The diver using lightweight gear, i.e., MK 21 MOD 1, or MK 20 MOD 0, is restricted under normal conditions to the limits described in Figure 4-11.

Air surface-supplied deep-sea gear is used primarily for bottom work in depths up to 190 fsw. It offers the diver maximum thermal and physical protection from the environment and obstacles. The helmet protects the head from overhead obstructions, has minimum breathing resistance, and provides two-way voice communications. The controlled buoyancy associated with the inflatable dress makes it a desirable technique for working on muddy bottoms or conducting jetting, tunneling, or working where the reaction forces of tools are high. Because the diver's negative buoyancy is easily controlled, a SSDS allows diving in areas with strong currents. The overall protection, comfort, and duration afforded the diver permits using the SSDS to the maximum depth limits of air diving. The primary working drawbacks of using deep-sea gear lie in its cumbersome characteristics which restrict bottom movement, and a diminished vertical mobility for work in the water column. Dressing time, lengthly pre-dive setup procedures, weight of the gear, and additional tending personnel required also restrict ease of deployment. Figure 4-11 discusses depth restrictions for deep-sea diving.

4-6.2 Explosive Ordnance Disposal (EOD). Diving in the vicinity of ordnance combines the inherent risks of diving and the explosive hazards of the ordnance. Diving to investigate, render safe, or dispose of explosive ordnance found underwater, regardless of type or fuzing, will be accomplished by qualified EOD divers only. Ship security searches for limpet mines or improvised explosive devices may be conducted by non-EOD divers for the purposes of location only (Paragraph 4-4.4).

4-6.2.1 EOD Diving Guidelines. Only EOD divers shall attempt to render safe underwater ordnance or improvised explosive devices.

Generally, it is safer for divers to work in pairs rather than singly. However, to do so when diving on underwater influence ordnance doubles the diver bottom time expended, increases the risk to life from live ordnance detonation, and increases the risk of detonation caused by the additional influence signature of the second diver. The following factors must be considered when deciding whether to operate singly or in pairs:

- Experience of the diver
- Confidence of the team
- Type and condition of ordnance suspected
- Environmental conditions
- Degree of operational urgency required.

Consequently, the EOD Diving Officer may authorize the employment of a single untended diver when it is deemed that the ordnance hazard is greater than the hazard presented by diving. Simulated ordnance training senarios do not constitute a real threat, therefore single untended divers may not be utilized in training operations. The diver will be surface tended or marked by attaching a buoy to him.

4-6.2.2 EOD Standard Safety Procedures. The following standard safety procedures must be observed during EOD diving operations.

- An EOD Diving Officer will be on scene during all phases of an explosive ordnance disposal diving operation involving a Render Safe Procedure (RSP).
- When diving on unknown or influence ordnance, the standby diver's equipment will be the same type as the diver neutralizing the ordnance.

A single depth gauge and wrist watch may be used when diving with a partner and using a buddy line.

4-6.3 Choice of Technique. With four types of diving equipment available (SCUBA, lightweight, MK 20 MOD 0, and deep-sea SSDS), the factors to be considered in selecting the technique to be used for a dive are:

- Duration and depth of the dive
- Type of work to be performed
- Environmental conditions
- Time constraints.

A dive of extended length, even in shallow water, may require an air supply exceeding that which could be provided by SCUBA. Specific depth limits have been established for each type of diving gear. These are presented in Figure 4-11, and may not be exceeded without specific approval of the Chief of Naval Operations, and then only when operational necessity dictates.

The increase of air consumption with depth limits open-circuit SCUBA to 130 fsw for reasonable working dives. The hazards of nitrogen narcosis and decompression further limit open-circuit SCUBA to 190 fsw even for dives of short duration. Surface-supplied equipment is generally preferred between 130 and 190 fsw, although open-circuit SCUBA may be used under extreme circumstances. Decompression SCUBA dives and SCUBA dives deeper than 130 fsw shall be conducted only when dictated by operational necessity and with the concurrence of the Commanding Officer.

All open-circuit SCUBA dives beyond 100 fsw will employ twin cylinders, each with a capacity of at least 62.4 cubic feet.

4-7 SELECT EQUIPMENT AND SUPPLIES

Equipment procured for use in the U.S. Navy has been tested under stringent laboratory and field conditions to ensure that it will perform according to design specifications.

4-7.1 Authorized Diving Equipment. A vast array of equipment and tools is available for use in diving operations. NAVSEAINST 10560.2 (series) lists and identifies much of this equipment and categorizes diving equipment Authorized for Navy Use (ANU).

4-7.2 Air Supply. The quality of diver's breathing air is vitally important. Air supplies provided to the diver in tanks or through a compressor must meet five basic criteria:

(1) Air must conform to established standards of purity. Standards for diving air purity can be found in Chapter 6 and Appendix L.

(2) Adequate air supply must be available in accordance with Chapters 5 and 6.

(3) Flow to the diver must be sufficient (refer to appropriate equipment operations and maintenance manual for flow requirements).

(4) A secondary supply must be available for surface-supplied diving (Chapter 6).

(5) Adequate overbottom pressure must be maintained at the dive station.

Compressors used to charge SCUBA bottles, to fill air banks on board ship, or to supply air directly to divers, must also be specifically designated for use in diving operations. Such compressors are equipped with filters for removing contaminants from the air. When in use, the compressor inlets shall be carefully positioned to prevent contamination of the air from compressor engine exhaust, stack gas, or other shipboard exhaust.

Air for SCUBA operations is carried by the divers in individual cylinders. These cylinders are filled from a bank of high-pressure cylinders or with a high-pressure compressor (see Chapter 5).

4-7.2.1 Medium-Pressure. Medium-pressure (MP), high-capacity compressors are used for

Normal and Maximum Limits for Air Diving

Depth fsw (meters)	Limit for Equipment	Safety Notes
60 (18)	Surface-supplied lightweight (air) diving equipment, max working limit without Emergency Gas Supply (EGS)	
60 (18)	MK 20 MOD 0 equipment with EGS	1
60 (18)	Max depth for standby diver using a single cylinder	
100 (30)	Open-circuit SCUBA with single SCUBA bottle	1
130 (40)	Open-circuit SCUBA, normal working limit	1
130 (40)	MK 20 MOD 0 with SCUBA supply using first-stage regulator authorized to 130 fsw	
130 (40)	Surface-Supplied Lightweight with 3/8" air hose	
190 (58)	Open-circuit SCUBA, max working limit with Commanding Officer's permission	1
190 (58)	MK 20 MOD 0 with SCUBA supply using first-stage regulator authorized to 190 fsw with Commanding Officer's permission	
190 (58)	Diving without a Diving Medical Officer at the site	2
190 (58)	Surface-supplied lightweight (air) diving equipment, max working limit with 1/2" air hose	2, 3
190 (58)	Surface-supplied deep-sea (air) diving equipment, normal working limit	2, 3
285 (87)	Surface-supplied deep-sea (air) diving equipment, max working limit, exceptional exposure	2,3

General Information:

(1) These limits are based on a practical consideration of working time versus decompression time and oxygen-tolerance limits. These limits shall not be exceeded except by specific authorization from the Chief of Naval Operations (CNO).

(2) Do not exceed the limits for exceptional exposures of the Standard Air Decompression Table.

(3) All planned air decompression dives deeper than 130 fsw require a certified recompression chamber on site.

(4) In an emergency, any operable recompression chamber may be used for treatment if deemed safe to use by the Diving Supervisor.

(5) Planned Exceptional Exposure dives require prior CNO approval. The Exceptional Exposure Tables, printed in red in the Standard Air Tables, have a significant higher probability of DCS.

Safety Notes:

(1) Under normal circumstances, do not exceed the limits of the N0-Decompression Table. Dives requiring decompression may be made if considered necessary by the Commanding Officer of the diving command. The total time of a SCUBA dive (including decompression) must never exceed the duration of the apparatus in use, disregarding any reserves.

(2) A Diving Medical Officer is required on-site for all air dives deeper than 190 fsw, where the maximum working depth of the diving apparatus may be exceeded, or for exceptional exposure dives.

(3) For MK 15/16 UBA ops, MK 4 with four 31-gram CO_2 cartridges (NSN 9C-4220-00-965-0595) conforming to MIL-C-16385 Type II must be used. For all SCUBA ops, four 17-gram cartridges (NSN 9C-4220-00-287-3741) conforming to MIL-C-16385 Type I or four 25-gram cartridges (NSN 9C-4220-00-272-0585) conforming to MIL-C-25369 Type I may be used. When using MIL-C-16385 Type I cartridges for dives between 130-190 feet, min allowable CO_2 weight is 17-grams. Buoyancy compensators and life jackets are authorized to 190 fsw when an outside source of inflation (either a pony bottle or the diver's SCUBA cylinder) is used.

Figure 4-11. Normal and Maximum Limits for Air Diving.

surface-supplied diving. These compressors can be portable or permanently installed in the support ship or craft.

4-7.2.2 High-Pressure. High-pressure (HP), high-capacity compressors are generally installed and are used for SCUBA charging, but may also supply low-pressure systems. High-pressure, low-capacity compressors are generally portable and used exclusively for charging SCUBA cylinders.

4-7.3 Oxygen. Pure oxygen is used for surface decompression and recompression treatments. When used with O_2 Surface Decompression procedures, oxygen greatly reduces diver in-water decompression time. Recompression treatment tables using oxygen (Tables 4, 5, 6, 6a, 7 and 8) are much more effective than the air treatment tables (Tables 1a, 2a, 3, and 4) which are used when no oxygen is available (Chapter 8). Purity standards for oxygen are found in Appendix L.

4-7.4 Diving Craft and Platforms. Craft used for diving operations (Figure 4-12), regardless of the technique being supported, should:

- Be seaworthy
- Include required lifesaving and other safety gear
- Have a reliable engine (unless it is a moored platform or barge)
- Provide ample room for the divers to dress
- Provide adequate shelter and working area for the support crew
- Be able to carry safely all equipment required for the operation
- Have a well-trained crew

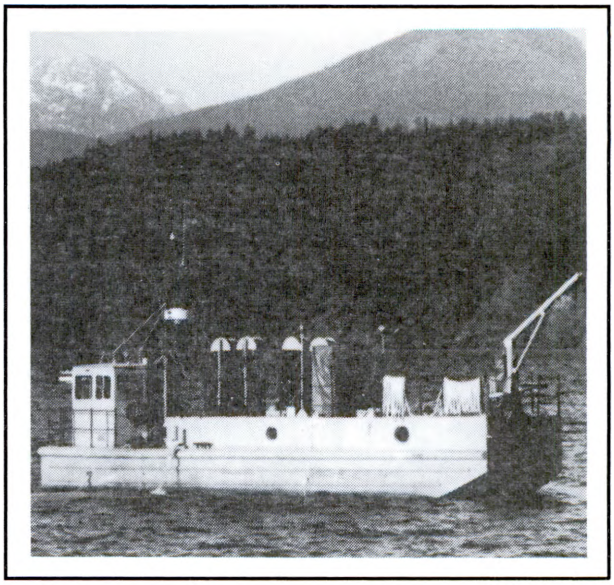


Figure 4-12. Surface-Supplied Diving Boat.

Other support equipment including barges, tugs, floating cranes, or vessels and aircraft for area search may be needed depending on the type of operation. The need for such additional equipment should be anticipated as far in advance as possible.

4-7.4.1 Deep-Sea Salvage/Rescue Diving Platforms.

- **Auxiliary Rescue/Salvage Ship (ARS) (Safeguard/Bolster Class).** The mission of the ARS ship is multiple: assisting disabled ships, debeaching stranded vessels, firefighting alongside other ships, lifting heavy objects, recovering submerged objects, towing other vessels, and performing manned diving operations. The ARS class ships carry a compliment of divers to perform underwater ship husbandry tasks and salvage operations as well as underwater search and recovery. This class of vessel is equipped for all air diving techniques. Onboard equipment allows diving with air to a depth of 190 fsw.
- **Submarine Rescue Ships (ASR) (Chanticleer Class).** These ships are designated

specifically for submarine rescue. Each ship in this class is equipped with powerful pumps, heavy air compressors, and special mooring equipment. The Chanticleer Class ASRs support air and helium-oxygen diving operations to a depth of 300 fsw and employ the McCann Rescue Chamber for submarine personnel rescue operations. The ASR design provides a large deck working area.

- **Submarine Rescue Ships (ASR) (Pigeon Class).** The Pigeon Class ships are the first ships designed specifically for submarine rescue. The Pigeon Class ships serve as surface support ships for the Deep Submergence Rescue Vehicles (DSRVs), rescue ships employing the existing McCann Rescue Chamber, major deep-sea diving support ships, and operational control ships for salvage operations. The installed saturation diving system consists of two deck decompression chambers (DDCs), two personnel transfer capsules (PTCs) to transport divers between the ship and dive depth, and associated support equipment. Submarine Rescue Ships are capable of supporting helium-oxygen diving to a depth of 950 fsw.

- **Salvage and Rescue Ship (ATS) (Edenton Class).** These ships, designed specifically for salvage operations, are capable of ocean towing, supporting diving operations, fighting shipboard fires, and lifting submerged objects that weigh as much as 300 tons from a depth of 120 fsw by static tidal lift or that weigh as much as 15 tons by dynamic lift. Equipped with both air and mixed-gas diving capabilities, these vessels can conduct diving operations to 300 fsw.

- **Submarine Tender (AS).** L.Y. Spear Class ships are the first U.S. submarine tenders designed specifically for servicing nuclear propelled attack submarines. Specially modified tenders expand support to attack submarines. Each ship can provide services to four submarines moored alongside simultaneously. The Simon Lake Class submarine tender is designed to repair and supply as many as three Fleet Ballistic Missile Submarines (SSBN) simultaneously.

- **Destroyer Tenders (AD)).** Destroyer tenders provide a wide range of repair and supply services to Destroyers and other ships. They are fitted with machine shops, parts storage, cranes and dive boats.

- **Fleet Ocean Tug (T-ATF).** In addition to towing, these large ocean going tugs serve as salvage and diving platforms. They are manned by a civilian crew with a military communications detachment and are operated by the Military Sealift Command.

- **Diving Tenders (YDT).** These vessels are used to support shallow-water diving operations. Two self-propelled diving tenders are in service in the U.S. Fleet (Phoebus YDT-14 and Suitland YDT-15). Two non-self-propelled YDTs are also in service.

4-7.4.2 Small Craft. SCUBA operations are normally conducted from small craft (Figure 4-13). These can range in size and style from an inflatable rubber raft with an outboard engine to a small landing craft. If divers are operating from a large ship or diving float, a small boat must be ready as a rescue craft in the event a surfacing diver is in trouble some distance from the support site. A small boat used by SCUBA divers must be able to slip its moorings quickly and move to a diver needing assistance.

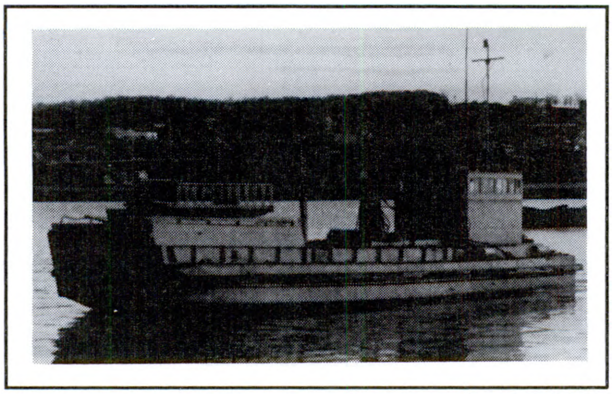


Figure 4-13. LCM Diving Boat.

4-8 SELECT AND ASSEMBLE THE DIVING TEAM

When planning diving assignments and matching the qualifications and experience of diving personnel to specific requirements of the operation, a thorough knowledge of the duties, responsibilities, and relationships of the various members of the diving team is essential.

The ultimate responsibility for the safe and successful conduct of all diving operations rests with the Commanding Officer. This includes planning, training, equipment readiness, safety, and accomplishment of the mission objectives. The Commanding Officer's responsibilities for diving operations are defined and specific authority is confirmed by the provisions of U.S. Navy Regulations and other fleet, force, or command regulations. To ensure diving operations are efficiently conducted, the Commanding Officer delegates appropriate authority to selected members of the command who, with subordinate personnel, make up the diving team. The diving team includes the Diving Officer, Master Diver, Diving Supervisor, Diving Medical Officer, divers qualified in various techniques and equipment, support personnel (tenders, qualified as divers if possible), recorder, and medical personnel as indicated by the type of operation (Figures 4-14 and 4-15). Other members of the ship's company, when properly instructed, provide support in varying degrees in such roles as

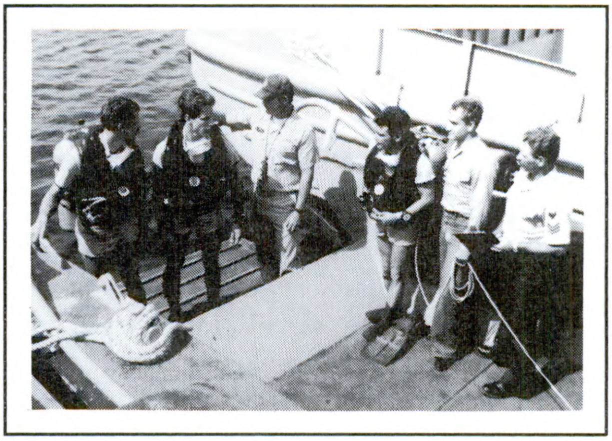


Figure 4-14. A SCUBA Diving Team Completes Predive Duties. The team includes a Diving Supervisor, two divers, one standby diver, one tender and a recorder.

Figure 4-15. A Dive Requiring One Diver. The team consists of a Diving Supervisor, the diver, a standby diver, two tenders per diver and a recorder.

boat crew, winch operators, and line handlers. The minimum number of personnel required on station for each particular type of diving equipment is discussed in Paragraph 4-8.5.8.

During the conduct of the dive, supervisory responsibilities may have to be transferred to accommodate new contingencies and circumstances. In some circumstances, a Master Diver may have to leave the immediate vicinity of the dive station. In this event, a Dive Supervisor qualified diver will assume the duties and responsibilities of the Diving Supervisor. In the absence of a Diving Officer, the Master Diver assumes the duties and responsibilities of the Diving Officer.

4-8.1 Diving Officer. The Diving Officer's primary responsibility is the safe conduct of all diving operations within the command. The Diving Officer is responsible for all diving operations and diver training undertaken by the command, and is responsible for verifying the qualifications and safe diving practices of all divers assigned. Although preferably a qualified diver, any commissioned officer may be assigned as a Diving Officer. All Diving Officers must be designated in writing. It is the responsibility of the Diving Officer to become thoroughly familiar with basic diving technique and have a detailed knowledge of all applicable regulations. The Diving Officer must ensure that equipment is properly configured, in good repair, well maintained, and correctly stowed. In addition, EOD Diving Officers must be trained and qualified in EOD diving techniques.

The Diving Officer is responsible for preparing the basic plans for all diving operations, subject to final approval by the Commanding Officer. The Diving Officer's activities are coordinated with shipboard departments and with other diving units that may be involved. All participants in a diving mission are thoroughly briefed on the mission, and the Diving Officer ensures they understand all applicable safety regulations and emergency procedures. The Diving Officer must establish a continuing training program, including frequent drills in emergency procedures.

4-8.2 Master Diver. The Master Diver is the most qualified person to supervise air and mixed-gas dives using SCUBA and surface-supplied diving equipment, and recompression treatments. He is directly responsible to the Diving Officer or, in the Diving Officer's absence, to the Commanding Officer, for the safe conduct of diving operations. The Master Diver is proficient in operating Navy approved underwater breathing equipment, support systems, and recompression chambers. He is also skilled in diagnosing and treating diving injuries and illnesses, particularly those requiring recompression therapy. The Master Diver is thoroughly familiar with operation and emergency procedures for diving systems and possesses a working knowledge of gas mixing and analysis, computations, salvage theory and methods, submarine rescue procedures, towing, and underwater ship husbandry. The Master Diver manages preventive and corrective maintenance on diving equipment, support systems, salvage machinery, handling systems, and submarine rescue equipment.

Training and requalification of divers attached to the command is conducted by the Master Diver, who also ensures that divers are trained in emergency procedures. The Master Diver recommends to the Commanding Officer, via the Diving Officer, which enlisted divers are qualified to serve as Diving Supervisors. The Master Diver must possess a comprehensive knowledge of the scope and application of all Naval instructions and publications pertaining to diving and must ensure that logs and reports are maintained and submitted as required.

The Master Diver oversees the efforts of the Diving Supervisor and provides advice and technical expertise. If circumstances warrant, the Master Diver will relieve the Diving Supervisor and assume control of the dive station. The Master Diver ensures that all phases of the diving operations are conducted safely.

4-8.3 Diving Supervisor. While the Master Diver is in charge of the overall diving operation, the Diving Supervisor is in charge of the actual diving operation for a particular dive or series of dives. No diving operations shall be conducted without the presence of the Diving Supervisor, who may be commissioned or enlisted depending on the size of the operation and the availability of qualified personnel. When appointing a Diving Supervisor from the enlisted ranks, selection is based on knowledge, experience, level of training and the seniority of the available personnel in the following order:

(1) Master Diver

(2) First Class Diver

(3) Diving Medical Technician

(4) Second Class Diver

(5) SCUBA Diver

Regardless of rank, the Diving Supervisor must be a qualified diver of demonstrated ability and experience. The Diving Supervisor must be designated in writing by the Commanding Officer. Diving Supervisors under instruction shall stand their watches under the supervision of a qualified, designated Diving Supervisor.

The Diving Supervisor, in close coordination with the Master Diver, assists the Diving Officer in preparing for an operation and plans the operation step-by-step. The Diving Supervisor must consider all possible contingencies, determine equipment requirements, recommend diving assignments, and establish back-up requirements for the operation. The Diving Supervisor shall be familiar with all divers on the team, and be able to evaluate the qualifications and physical fitness of the divers selected for a particular job. The Diving Supervisor inspects all equipment and conducts predive briefings of personnel. While the operation is underway, the Diving Supervisor monitors progress; debriefs divers; updates instructions to subsequent divers; and ensures that the Master Diver, Diving Officer, Commanding Officer, and other personnel as necessary are advised of progress and of any changes to the original plan. The Diving Supervisor should not hesitate to call upon the technical advice and expertise of the Master Diver during the conduct of the dive operation. When the mission has been completed, the Diving Supervisor gathers appropriate data, analyzes the results of the mission, prepares reports for submission to higher authority, and ensures that required records are completed. These records may range from equipment logs to individual diving records.

4-8.4 Diving Medical Officer. The Diving Medical Officer (Figure 4-16) defines the proper course of medical action during medical emergencies such as those described in Chapter 8. The Diving Medical Officer provides on-site medical care for divers as conditions arise and ensures that diving personnel receive proper attention before, during, and after dives. Only the Diving Medical Officer is authorized to modify recompression treatment specified in Chapter 8, with the concurrence of the Commanding Officer. A Diving Medical Officer is required on site for all air dives deeper than 190 fsw, when the maximum working depth of the diving apparatus may be exceeded, or for exceptional exposure air dives.

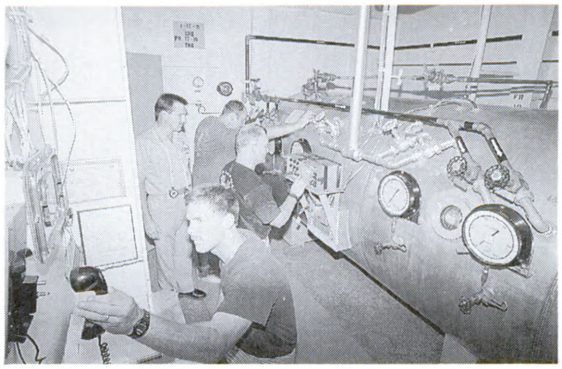


Figure 4-16. The Master Diver Supervising a Recompression Treatment.

4-8.5 Diving Personnel. Navy divers must be qualified and designated in accordance with instructions issued by the Naval Military Personnel Command (NMPC). The diver selected for an operation must be qualified for the diving technique used, the particular equipment involved, and for diving to the depth required.

Diving personnel assigned to the Navy Experimental Diving Unit (NEDU), Naval Medical Research Institute (NMRI), and Naval Submarine Medical Research Laboratory (NSMRL) are exempt from such requirements because they are assigned as experimental diving test subjects, and may be employed in any dive profile required within approved test protocols.

While working, the diver must keep topside personnel informed of conditions on the bottom, progress of the task, and of any developing problems which may indicate the need for changes to the plan or a call for assistance from other divers. To ensure safe conduct of the dive, the diver must always obey a signal from the surface and repeat all commands when using voice communications. The diver is responsible for the diving gear worn and must ensure that it is complete, in good repair, and ready for use at any time.

4-8.5.1 Standby Diver. A standby diver with a tender is required for all diving operations. The standby diver need not be equipped with the same equipment as the primary diver (except as otherwise specified), but must have equivalent depth and operational capabilities. SCUBA cannot be used for the standby diver for surface-supplied diving operations.

The standby diver is a fully qualified diver, assigned for back up or to provide emergency assistance, and is ready to enter the water immediately. For surface-supplied operations, the standby diver must be dressed to the following points: MK 12 to the breech ring; MK 21 MOD 1 with strain relief ready to connect to the harness. Under certain conditions, the Diving Supervisor may require that the helmet be worn. A standby SCUBA diver shall don all equipment and be checked by the Diving Supervisor. The standby diver may then remove tank, mask, and fins and have them ready to don immediately for quick deployment. The standby diver receives the same briefings and instructions as the working diver, monitors the progress of the dive and is fully prepared to respond if called upon for assistance. The standby diver shall be equipped with an octopus rig.

The standby diver may be deployed as a working diver provided all of the following conditions are met:

- Surface-supplied no-decompression dive of 60 fsw or less
- Ship husbandry, underwater construction dive or aviation underwater egress training
- Same job/location i.e., working on port and starboard propellers on the same vessel

Prior to deployment of the standby diver, the work area must be determined to be free of hazards (i.e., suctions, discharges) by the first diver on the job site.

When working in ballast tanks or confined spaces, the standby diver may be deployed as a working diver, and both divers will be tended by a third diver who is outside the confined space (see also paragraph 4-4.9).

The standby diver must remain on deck ready for deployment when a salvage dive is being done.

4-8.5.2 Buddy Diver A buddy diver is the diver's partner for a SCUBA operation. The buddy divers are jointly responsible for the assigned mission. Each diver keeps track of depth and time during the dive. Each diver must watch out for the safety and well being of his buddy, and must be alert for symptoms of nitrogen narcosis, decompression sickness, and carbon dioxide intoxication. A diver must keep his buddy within sight and never leave his buddy alone except to obtain additional assistance in an emergency. If visibility is limited, a buddy line should be used to maintain contact. If SCUBA divers get separated and can not locate each other, both divers shall surface immediately.

4-8.5.3 Diver Tender. The tender is the surface member of the diving team who works most closely with the diver on the bottom. At the start of a dive, the tender checks the diver's equipment and topside air supply for proper operation and dresses the diver. Once the diver is in the water, the tender constantly tends the lines to eliminate excess slack or tension. The tender exchanges line-pull communications with the diver, keeps the Diving Supervisor informed of the amount of diving hose/tending line over the side, and remains alert for any signs of an emergency.

The tender should be a qualified diver. When circumstances require the use of a non-diver as a tender, the Diving Officer, Master Diver and Diving Supervisor must ensure that the tender has been thoroughly instructed in the required duties. If a substitute tender must be employed during an operation, the Diving Supervisor must make certain that the substitute is adequately briefed before assuming duties.

4-8.5.4 Recorder. The recorder must be a qualified diver. He maintains worksheets, fills out the diving log for the operation, and records the diver's descent time, depth of dive, and bottom time. The recorder reports to the Diving Supervisor the ascent time, first stop, and time required at the decompression stop.

The recorder is required to have on hand a copy of the USN Standard Decompression Tables. When decompression begins, the schedule selected by the Diving Supervisor is recorded on the chart and log. The recorder keeps all members of the team advised of the status of the divers.

In SCUBA operations, the Diving Supervisor often assumes the duties of the recorder.

4-8.5.5 Medical Personnel. Diving Medical Officers and Diving Medical Technicians are given special training in hyperbaric medicine and in diving. They provide medical advice and treatment to diving personnel. They also instruct members of the diving team in first aid procedures, and participate in diving operations when the presence of diving medical personnel is indicated, as when particularly hazardous operations are being conducted.

Diving medical personnel evaluate the fitness of divers before operations begin and are prepared to handle any emergencies which might arise. They also observe the condition of other support personnel, and are alert for signs of fatigue, overexposure, and heat exhaustion.

4-8.5.6 Other Support Personnel. Other support personnel can include almost any member of the command when assigned to duties that support diving operations. Some personnel need specific indoctrination. Boat operators must understand diving procedures, know the meanings of signals, and be aware of the mission objectives. Other personnel, such as winch operators or deck crew, might interact with the operation directly, but only when under the control of the Diving Supervisor. Engineering personnel may be directed to secure overboard discharges and lock the shafts; a sonar operator might be required to secure equipment and put a "Do Not Energize" tag on the power switch (see Paragraph 4-9.3 for a detailed Ship Repair Safety Checklist).

The Officer of the Deck (OOD) or Command Duty Officer (CDO), is responsible to the Commanding Officer for the operation and safety of the ship and crew during the watch. He shall be concerned with the activities of the diving team. The OOD/CDO must stay informed of the progress of the operation, of any changes to the original plan, and shall be notified as far in advance as possible of any special requirements. The Officer of the Deck or Command Duty Officer must be alert for any shifting of the moor, or changing weather/sea conditions. He will inform the Diving Officer and/or Diving Supervisor of any changes in these conditions.

4-8.5.7 Cross-Training and Substitution. Each member of the diving team should be qualified to act in any position on the team. Because it is probable that substitutions will be made at some point during a lengthy mission, dive plans and diving schedules should organize personnel and work objectives so that experienced personnel will always be available on site. All personnel who participate in the operation should be included in initial briefings.

4-8.5.8 Manning Levels. The size of the diving team may vary with the operation, depending upon the type of equipment being used, the number of divers needed to complete the mission, and the depth. Other factors, such as weather, planned length of the mission, the nature of the objective, and the availability of various resources will also influence the size of the team.

Minimum manning levels for a variety of diving teams are found in Figure 4-17. The minimum levels must be maintained; levels should be increased as necessary to meet anticipated operational conditions and situations.

4-8.5.9 Physical Condition. Before beginning training as a diver, the candidate must meet the specific physical requirements for divers set forth by the Commander Naval Medical Command and pass a physical screening test as outlined in NMPC MANUAL, ART. 1410380. Once qualified, it is the diver's responsibility to maintain good health and top physical condition.

Medical personnel assigned to a diving unit shall take an active interest in the day-to-day condition of each diver, and the Diving Supervisor must verify the fitness of each diver immediately before a dive. Any symptom such as cough, nasal congestion, apparent fatigue, emotional stress, skin or ear infection is reason for placing the diver on the binnacle list until the problem is corrected.

Physical condition is often best judged by the diver who is obligated to report to the Diving Supervisor when not feeling fit to dive. A diver who, for any reason, does not want to make a dive should not be forced. A diver who regularly declines diving assignments shall be disqualified as a diver.

4-8.6 Underwater Salvage or Construction Demolition Personnel. Underwater salvage demolition personnel are formally trained in underwater precision explosives techniques and hold Navy Enlisted Classification (NEC) 5375. Salvage/Construction Demolition Diver personnel must be currently certified and designated in accordance with the requirements specified in OPNAVINST 8023.2 series.

4-8.6.1 NEC 5375 Personnel. The assigned Salvage/Construction Demolition Diver NEC 5375 is responsible to provide to the Commanding Officer a comprehensive and written blasting plan which contains the following minimum information:

- Demolition team organization
- Work description with alternatives
- Range standard operating procedures
- Prefiring procedures
- Postfiring procedures
- Area security plan

Minimum Personnel Levels for Air Diving Stations

	EOD SCUBA		SCUBA Operations		Surface-Supplied Operations		
	Single Diver	Buddy Pair	Single Diver	Buddy Pair	Diver's Helmet MK 21 MOD 1	MK 20 MOD 0	SSDS MK 12
Diving Supervisor	1	1	1	1	1	1	1
Comms and Logs	(a)	(a)	(a)	(a)	1	1	1
Console Operator					(k)	(k)	1
Diver (b)	1	2	1	2	1	1	1
Standby Diver	1	1	1	1	1	1	1
Diver Tender (b, c)	1 (d)		1		1	1	1
Standby Diver Tender	(i)	(j)	(i)	1	1	1	1
Total	4 (f, h, i)	4 (h)	4 (e, g, h, j)	5 (h)	6	6 (g)	7

WARNING
These are the minimum personnel levels required, below which diving operations are not permitted. Circumstances may require that these minimum personnel levels be increased so the diving operations can be conducted safely.

NOTES:

(a) Diving Supervisor may fill requirement for Comms and Logs for SCUBA operations.

(b) Each additional surface-supplied diver or tended SCUBA diver will require an additional tender. The number of surface-supplied divers may be increased as necessary to the extent that the air system can support them.

(c) SCUBA divers, except SPECWAR divers, must be surface tended if direct ascent to surface is not available, such as when diving under the bilge keel. Situations may require that a diver be tended by a second diver situated at the bilge keel.

(d) The EOD Diving Officer may authorize a single untethered EOD diver when disarming live ordnance in an operational (non-training) situation.

(e) Submarines that have only three qualified SCUBA divers assigned are authorized to conduct dives with a non-diver Commissioned Officer acting as the Diving Supervisor. In all cases, submarines will endeavor to obtain the prerequisite number of qualified divers to support their mission. All other commands are to conduct all SCUBA diving operations with a minimum of four divers.

(f) EOD Diving Officers are required for all EOD Operations involving Render Safe Procedures (RSP).

(g) Manning levels for Dilbert Dunkers and Device 9D5 pool pilot training which require safety SCUBA divers are covered by directives promulgated by NAWSTP Safety Diver Operations.

(h) Chase boat is required for SCUBA diving operations when conditions exist where the diver could be displaced from the dive site (i.e., bottom search in a strong current or a long duration swim).

(i) If the Standby Diver is deployed, the Diving Supervisor will tend the Standby Diver.

(j) If the Standby Diver is deployed in the tethered mode, the Diving Supervisor will tend the Standby Diver.

(k) Comms and Logs may serve as Console Operator on diving boats when performing ship husbandry.

Figure 4-17. Minimum Personnel Levels for Air Diving Stations.

- Misfire procedures

- Personnel and equipment casualty procedures

- Blasting sequence of events

The NEC 5375 should direct all phases of demolition operations using only approved operating and safety procedures. The NEC 5375 will ensure the operation is not allowed to proceed until receiving specific approval from the Diving Supervisor, and will take charge of all misfires, ensuring they are handled in accordance with the approved plan.

4-8.6.2 Explosive Handlers. All divers who handle explosives must be trained and certified in accordance with OPNAVINST 8023.2 series. They must work under the supervision of underwater Salvage/Construction Demolition Diver personnel who are formally qualified to conduct underwater demolition operations.

4-9 ORGANIZE AND SCHEDULE OPERATIONS

4-9.1 Task Planning and Scheduling. In developing a detailed task-by-task schedule for an operation, the following points should be considered.

All phases of an operation are important. A common failure in planning is to put excessive emphasis on the actual dive phases, while not fully considering predive and postdive activities. Another failure is to treat operations of a recurring nature with an indifference to safety that comes with overfamiliarity.

- The schedule should allocate sufficient time for preparation, transit to the site, rendezvous with other vessels or units, and establishing a secure mooring.

- Bottom time is always at a premium, and all factors which will affect bottom time must be carefully considered. These include depth, decompression, number of divers available, support craft size, and surface and underwater environmental conditions.

- The number and profile of repetitive dives in a given time period are limited. This subject is discussed in Chapter 7.

- Plans should include the option to work night and day; however, the increased risk of a diving mishap from fatigue should be considered.

- The level of personnel support depends on the diving techniques selected (see Minimum Manning Levels, Figure 4-17).

- In planning tasks, non-diving topside support personnel must be selected carefully, especially those who are not members of the diving team.

- Any schedule must be flexible to accommodate unexpected complications, delays, and changing conditions.

- The Diving Supervisor must anticipate difficulties and be prepared to overcome them or find alternative methods to circumvent them.

- If divers have been inactive and operating conditions permit, workup dives should be conducted in-water or in the recompression chamber.

4-9.2 Postdive Tasks. A diving operation is completed when the objective has been met, the diving team demobilized, and records and reports are filed. Time should be allocated for:

- Recovering, cleaning, inspecting, maintaining, repairing, and stowing all equipment

- Disposition of materials brought up during the operation
- Debriefing divers and other team members
- Analyzing the operation, as planned and as actually carried out
- Restocking expended materials
- Ensuring the readiness of the team to respond to the next assignment

4-10 BRIEF THE DIVING TEAM

The operations plan will only be successful if each member of the diving team fully understands the dive plan, and the roles of other members of the diving team and various support personnel.

4-10.1 Establish Mission Objective. The Master Diver or the Diving Supervisor should brief the team on the overall mission and the aspects of the operation necessary to safely achieve the objective. Major points of discussion include:

- Clear, brief statement of the mission objective
- Dominant factors that may determine mission outcome (i.e., environment, enemy/friendly actions and hazards)
- Major subtasks required to accomplish the mission
- Time factors that may prevail
- Any changes or augmentations of the dive plan

Prior to starting a dive mission or dive day, coordination with other commands or shipboard departments should be accomplished.

4-10.2 Identify Tasks and Procedures. A briefing can be elaborate or simple. For large operations, a formal briefing with charts, slides, and diagrams might be required. For most operations, the briefing need not be complex and may be simply an informal meeting. The briefing should present a detailed task breakdown of the dive objective, primary tasks, diving procedures, and related work procedures for the mission or dive day. Diving personnel must understand diving and work procedures. Information from prior debriefings will help the Diving Officer and Diving Supervisor to tailor the dive plan. Prompt debriefing of divers returning to the surface will provide the Diving Supervisor with information that may influence or alter the next phase of the operation. Divers should be questioned about the progress of the work, bottom conditions, and anticipated problems. They should also be asked for suggestions for immediate changes.

4-10.3 Review Diving Procedures. Diving procedures should be reviewed during the briefing. This review may include:

- Use of diving equipment and tools
- Procedural information from NAVSEA diving advisories
- Supply of necessary materials, breathing gas and other expendibles
- Use of Predive Checklists and Diving Operations Checklists

The Diving Safety and Planning Checklist (Figure 4-18), Ship Repair Safety Checklist for Diving (Figure 4-19), and the Surface- Supplied Diving Operations Predive Checklist (Figure 4-20) support control of diving operations.

These checklists should be tailored to specific missions and environmental circumstances. They can be used by supervisors and team members to ensure that all safety- and mission-related factors are checked prior to and during a diving operation.

4-10.4 Assignment of Personnel. The following aspects of personnel assignments may be included in the briefing.

- Number and type of personnel needed (i.e., EOD, SEALS, surface-support divers, medical personnel, ROV operator, etc.)
- Personnel availability (i.e., health, special skills, and experience)
- Notification of personnel of future work assignments so preparation and planning can be accomplished in an orderly fashion

4-10.5 Assistance and Emergencies. In any diving operation, three types of assistance may be required:

(1) Additional equipment, personnel, supplies, or services.

(2) Clarification, authorization, or decisions from higher command.

(3) Emergency assistance in the event of an accident or serious illness.

Unexpected developments or emergency situations usually are accompanied by confusion. The source and availability of any needed assistance, and the method for obtaining it as quickly as possible, must be determined in advance. The location of the nearest recompression chamber must be identified and the chamber operators notified before the operation begins. The sources of emergency transportation, military or civilian, must be established and alerted, and the nearest Diving Medical Officer should be located and notified. Arrangements must be made to ensure a 24-hour availability for emergency assistance.

When a recompression chamber is required to support surface decompression and the fulfillment of depth/time limitations, the chamber must be certified. In an emergency, if a recompression chamber is required and in the opinion of the Diving Supervisor is safe to operate, a non-certified chamber may be used.

Figure 4-21 is a suggested Emergency Assistance Checklist that should be completed and posted at the diving station to provide necessary information so that any member of the team could take prompt action.

4-10.5.1 Notification of Ship's Personnel. In the event of a diving casualty or mishap on dive station, calm must be maintained. Maintain silence on the side and take orders from the Diving Officer, Master Diver and/or Diving Supervisor.

4-10.5.2 Fouling and Entrapment. Fouling and entrapment are more common with surface-supplied gear than SCUBA because of the ease with which the umbilicals can become entangled. Divers must be particularly careful and watch their own umbilicals and those of their partners as well.

The surface-supplied diver may become fouled more easily, but will usually have an ample air supply while working to get free. The SCUBA diver may have no other recourse but to remove the gear and make a free ascent. If trapped, the SCUBA diver must face the possibility of running out of air before being able to work free.

The first and most important action that a trapped diver can take is to stop and think. The diver must remain calm, analyze the situation, and carefully try to work free. Panic and over-

DIVING SAFETY AND PLANNING CHECKLIST
(Sheet 1 of 5)

STEPS IN PLANNING OF DIVING OPERATIONS
Detailed, advanced planning is the foundation of diving safety.

A. ANALYZE THE MISSION FOR SAFETY.

__ Ensure mission objective is defined.
__ Determine that non-diving means of mission accomplishment have been considered and eliminated as inappropriate.
__ Coordinate emergency assistance.
__ Review relevant Naval Warfare Publications (NWP) and OPNAV instructions.

B. IDENTIFY AND ANALYZE POTENTIAL HAZARDS.

__ **Natural Hazards:**

1. Atmospheric:
   ___ Exposure of personnel to extreme conditions
   ___ Adverse exposure of equipment and supplies to elements
   ___ Delays or disruption caused by weather
2. Surface:
   ___ Sea sickness
   ___ Water entry and exit
   ___ Handling of heavy equipment in rough seas
   ___ Maintaining location in tides and currents
   ___ Ice, flotsam, kelp, and petroleum in the water
   ___ Delays or disruption caused by sea state
3. Underwater and Bottom:
   ___ Depth which exceeds diving limits or limits of available equipment
   ___ Exposure to cold temperatures
   ___ Dangerous marine life
   ___ Tides and currents
   ___ Limited visibility
   ___ Bottom obstructions
   ___ Ice (underwater pressure ridges, loss of entry hole, loss of orientation, etc.)
   ___ Dangerous bottom conditions (mud, drop-offs, etc.)

__ **On-Site Hazards:**
   ___ Local marine traffic or other conflicting naval operations
   ___ Other conflicting commercial operations
   ___ High-powered, active sonar
   ___ Radiation contamination and other pollution (chemical, sewer outfalls, etc.)

Figure 4-18. Diving Safety and Planning Checklist (sheet 1 of 5).

DIVING SAFETY AND PLANNING CHECKLIST (Sheet 2)

__ **Mission Hazards:**
- ___ Decompression sickness
- ___ Communications problems
- ___ Drowning
- ___ Other trauma (injuries)
- ___ Hostile action

__ **Object Hazards:**
- ___ Entrapment and entanglement
- ___ Shifting or working of object
- ___ Explosives or other ordnance

C. SELECT EQUIPMENT, PERSONNEL, AND EMERGENCY PROCEDURES.

__ **Diving Personnel:**

___ 1. Assign a complete and properly qualified Diving Team.

___ 2. Assign the right man to the right task.

___ 3. Verify that each member of the Diving Team is properly trained and qualified for the equipment and depths involved.

___ 4. Determine that each man is physically fit to dive, paying attention to:
- ___ general condition and any evidence of fatigue
- ___ record of last medical exam
- ___ ears and sinuses
- ___ severe cold or flu
- ___ use of stimulants or intoxicants

___ 5. Observe divers for emotional readiness to dive:
- ___ motivation and professional attitude
- ___ stability (no noticeably unusual or erratic behavior)

__ **Diving Equipment:**

___ 1. Verify that diving gear chosen and diving technique are adequate and authorized for mission and particular task.

___ 2. Verify that equipment and diving technique are proper for depth involved.

___ 3. Verify that life support equipment has been tested and approved for U.S. Navy use.

___ 4. Determine that all necessary support equipment and tools are readily available, and are best for accomplishing job efficiently and safely.

___ 5. Determine that all related support equipment such as winches, boats, cranes, floats, etc. are operable, safe, and under control of trained personnel.

___ 6. Check that all diving equipment has been properly maintained (with appropriate records) and is in full operating condition.

Figure 4-18. Diving Safety and Planning Checklist (sheet 2 of 5).

DIVING SAFETY AND PLANNING CHECKLIST (Sheet 3)

__ **Provide for Emergency Equipment:**

___ 1. Obtain suitable communications equipment with sufficient capability to reach outside help; check all communications for proper operation.

___ 2. Verify that a recompression chamber is ready for use, or notify the nearest command with one that its use may be required within a given time frame.

___ 3. Verify that a completely stocked first aid kit is at hand.

___ 4. If oxygen will be used as standby first aid, verify the tank is full, properly pressurized, and masks, valves, and other accessories are fully operable.

___ 5. If a resuscitator will be used, check apparatus for function.

___ 6. Check that fire-fighting equipment is readily available and in full operating condition.

___ 7. Verify emergency transportation is either standing by or on immediate call.

__ **Establish Emergency Procedures:**

___ 1. Know how to obtain medical assistance immediately.

___ 2. For each potential emergency situation, assign specific tasks to the diving team and support personnel.

___ 3. Complete and post Emergency Assistance Checklist; ensure that all personnel are familiar with it.

___ 4. Verify that an up-to-date copy of the U.S. Navy Decompression Tables is available.

___ 5. Ensure that all divers, boat crews, and other support personnel understand all diver hand signals.

___ 6. Predetermine distress signals and call-signs.

___ 7. Ensure that all divers have removed anything from their mouths on which they might choke during a dive (gum, dentures, tobacco).

___ 8. Thoroughly drill all personnel in Emergency Procedures, with particular attention to cross-training; drills should include:

Emergency recompression	Rapid undressing
Fire	First aid
Rapid dressing	Embolism
Restoration of breathing	Drowning
Electric shock	Blowup
Entrapment	

D. ESTABLISH SAFE DIVING OPERATIONAL PROCEDURES.

__ **Complete Planning, Organization, and Coordination Activities:**

___ 1. Ensure that **other** means of accomplishing mission have been considered before deciding to use divers.

___ 2. Ensure that contingency planning has been conducted.

___ 3. Carefully state goals and tasks of each mission and develop a flexible plan of operations (Dive Plan).

___ 4. Completely brief the diving team and support personnel (paragraph 4.10).

___ 5. Designate a Master Diver or properly qualified Diving Supervisor to be in charge of the mission.

Figure 4-18. Diving Safety and Planning Checklist (sheet 3 of 5).

DIVING SAFETY AND PLANNING CHECKLIST (Sheet 4)

___ 6. Designate a recorder/timekeeper and verify that he understands his duties and responsibilities.

___ 7. Determine the exact depth at the job-site through the use of a lead line, pneumofathometer, or commercial depth sounder.

___ 8. Verify existence of an adequate supply of compressed air available for all planned diving operations **plus an adequate reserve for emergencies.**

___ 9. Ensure that no operations or actions on part of diving team, support personnel, technicians, boat crews, winch operators, etc., take place without the knowledge of and by the direct command of the Diving Supervisor.

___ 10. All efforts must be made through planning, briefing, training, organization, and other preparations to minimize bottom time. Water depth and the condition of the diver (especially fatigue), rather than the amount of work to be done, shall govern diver's bottom time.

___ 11. Current decompression tables must be on hand and must be used in all planning and scheduling of diving operations.

___ 12. Instruct all divers and support personnel not to cut any lines until approved by the Diving Supervisor.

___ 13. Ensure that ship, boat, or diving craft is securely moored and in position to permit safest and most efficient operations (exceptions are emergency and critical ship repairs).

_ 14. Verify that, when using surface-supplied techniques, the ship, boat, or diving craft has at least a two-point moor.

___ 15. Ensure that, when conducting SCUBA operations in hazardous conditions, a boat can be quickly cast off and moved to a diver in distress.

__ **Perform Diving Safety Procedures, Establish Safety Measures:**

___ 1. **Ensure that each diver checks his own equipment** in addition to checks made by tenders, technicians, or other support personnel.

___ 2. Designate a standby diver for all diving operations; standby diver will be dressed to the necessary level and ready to enter the water if needed.

___ 3. Assign buddy divers, when required, for all SCUBA operations.

___ 4. Take precautions to prevent divers from being fouled on the bottom. If work is to be conducted inside a wreck or other structure, assign a team of divers to accomplish the task. One diver enters the wreck, the other tends his lines from point of entry.

___ 5. When using explosives, take measures to ensure that no charge will be fired while divers are in water.

___ 6. Use safety procedures as outlined in relevant naval publications for all underwater cutting and welding operations.

___ 7. Brief all divers and deck personnel on the planned decompression schedules for each particular dive. Check provisions for decompressing the diver.

___ 8. Verify that ship, boat, or diving craft is displaying proper signals, flags, day shapes, or lights to indicate diving operations are in progress. (Consult publications governing International or Inland Rules, International/Inland local signals, and Navy communications instructions.)

Figure 4-18. Diving Safety and Planning Checklist (sheet 4 of 5).

DIVING SAFETY AND PLANNING CHECKLIST (Sheet 5)

___ 9. Ensure that protection against harmful marine life has been provided. (See Appendix I.)
___ 10. Check that the quality of diver's air supply is periodically and thoroughly tested to ensure purity.
___ 11. Thoroughly brief boat crew.
___ 12. Verify that proper safety and operational equipment is aboard small diving boats or craft.

__ **Notify Proper Parties that Dive Operations Are Ready to Commence:**
___ 1. Diving Officer
___ 2. Commanding Officer
___ 3. Area Commander
___ 4. Officer of the Deck/Day
___ 5. Commanding Officer of ships alongside
___ 6. Bridge, to ensure that ship's personnel **will not:**
  ___ turn the propeller or thrusters
  ___ get underway
  ___ activate active sonar or other electronics
  ___ drop heavy items overboard
  ___ shift the moor
  ___ operate rudder or steering mechanisms
___ 7. Ship Duty Officer, to ensure that ship's personnel **will not:**
  ___ activate sea discharges or suctions
  ___ operate bow or stern-planes or rudder
  ___ operate vents or torpedo shutters
  ___ turn propellers
___ 8. Other Interested Parties and Commands:
  ___ Harbor Master/Port Services Officer
  ___ Command Duty Officers
  ___ Officers in tactical command
  ___ Cognizant Navy organizations
  ___ U.S. Coast Guard (if broadcast warning to civilians is required)
___ 9. Notify facilities having decompression chambers and sources of emergency transportation that diving operations are underway and their assistance may be needed.

Figure 4-18. Diving Safety and Planning Checklist (sheet 5 of 5).

Ship Repair Safety Checklist for Diving

(Sheet 1 of 2)

When diving operations will involve underwater ship repairs, the following procedures and safety measures are required in addition to the Diving Safety Checklist.

SAFETY OVERVIEW.

A. The Diving Supervisor shall advise key personnel of the ship undergoing repair:

1. OOD
2. Engineer Officer
3. CDO
4. OODs of ships alongside
5. Squadron Operations (when required)
6. Combat Systems Officer

B. The Diving Supervisor shall request that OOD/Duty Officer of ship being repaired ensure that appropriate equipment is secured and tagged out.

C. The Diving Supervisor shall request that OOD/Duty Officer advise him when action has been completed and when diving operations may commence.

D. When ready, the Diving Supervisor shall request that the ship display appropriate diving signals and pass a diving activity advisory over the 1MC every 30 minutes. For example, "There are divers working over the side. Do not operate any equipment, rotate screws, cycle rudder, planes or torpedo tube shutters, take suction from or discharge to sea, blow or vent any tanks, activate sonar or underwater electrical equipment, open or close any valves, or cycle trash disposal unit before checking with the Diving Supervisor".

E. The Diving Supervisor shall advise the OOD/Duty Officer when diving operations commence and when they are concluded. At conclusion, the ship will be requested to pass the word on the 1MC, "Diving operations are complete. Carry out normal work routine".

F. Diving within 50 feet of an active sea suction (located on the same side of the keel) that is maintaining a suction of 50 gpm or more, is not authorized unless considered as an emergency repair and is authorized by the Commanding Officers of both the repair activity and tended vessel. When it is determined that the sea suction is maintaining a suction of more than 50 gpm and is less than 50 feet, or maintaining a suction of more than 50 gpm and is less than 50 feet but on the opposite side of the keel, the Diving Supervisor must determine if the sea suction is a safety hazard to the divers prior to conducting any diving operation. In all cases the Diving Supervisor must be aware of the tend of the diver's umbilical to ensure that it will not cross over or become entrapped by an active sea suction.

A. NOTIFY KEY PERSONNEL.

1. OOD ____________________ (signature)
2. Engineer Officer ____________________ (signature)
3. CDO ____________________ (signature)
4. OOD USS ____________________
   OOD USS ____________________
   OOD USS ____________________
   OOD USS ____________________
5. Squadron Operations ____________________
6. Port Services Officer ____________________

(Diving Supervisor (signature))

Figure 4-19. Ship Repair Safety Checklist for Diving (sheet 1 of 2).

Ship Repair Safety Checklist for Diving

(sheet 2 of 2)

B. TAG OUT EQUIPMENT.

TAG OUT	SIGNATURE AND RATE
Rudder	______________________
Planes	______________________
Torpedo tube shutters	______________________
Trash disposal unit	______________________
Tank blows	______________________
Tank vents	______________________
Shaft(s) locked	______________________
Sea suctions	______________________
Sea discharges	______________________
U/W electrical equipment	______________________
Sonars	______________________
Other U/W equipment	______________________
	______________________

USS ______________________
(name of ship)

OOD ______________________
(signature of OOD)

Figure 4-19. Ship Repair Safety Checklist for Diving (sheet 2 of 2).

Surface-Supplied Diving Operations Predive Checklist

(sheet 1 of 5)

CAUTION

This checklist is an overview intended for use with the detailed Operating Procedures (OPs) from the appropriate equipment O&M technical manual.

A. Basic Preparation:

____ 1. Verify that a recompression chamber, Diving Officer, and Diving Medical Officer will be present on the diving station for dives of more than 190 feet.

____ 2. Verify that proper signals indicating underwater operations being conducted are displayed correctly.

____ 3. Ensure that all personnel concerned, or in the vicinity, are informed of diving operations.

____ 4. Determine that all valves, switches, controls, and equipment components affecting diving operation are tagged-out to prevent accidental shut-down or activation

____ 5. Verify that diving system and recompression chamber are currently certified or granted a Chief of Naval Operations (CNO) waiver to operate.

B. Equipment Preparation:

____ 1. Assemble all members of the diving team and support personnel (winch operators, boat crew, watchstanders, etc.) for a predive briefing.

____ 2. Assemble and lay out all dive equipment, both primary equipment and standby spares for diver (or standby diver), including all accessory equipment and tools.

____ 3. Check all equipment for superficial wear, tears, dents, distortion, or other discrepancies.

____ 4. Check all masks, helmets, view ports, faceplates, seals, and visors for damage.

____ 5. Check all belts, laces, strain reliefs, and lanyards for wear; renew as needed.

C. Surface Support Diving System MK 12:

____ Ensure that all Operating Procedures (OPs) have been completed in accordance with SSDS MK 12 Technical Manual, NAVSEA 0994-LP-018-5010.

D. Surface Supplied Lightweight Gear (MK 21 MOD1)

____ Ensure that all Operating Procedures (OPs) have been completed in accordance with UBA MK 21 MOD 1 Technical Manual, NAVSEA S6560-AG-OMP-010-UBA-21/1.

Figure 4-20. Surface-Supplied Diving Operations Predive Checklist (sheet 1 of 5).

Surface-Supplied Diving Operations Checklist

(sheet 2 of 5)

E. MK 20 MOD 0:

_____ Ensure that all Operating Procedures (OPs) have been completed in accordance with UBA MK 20 MOD 0 Technical Manual, NAVSEA SS600-AK-MMO-010/MK 20 MOD 0.

F. General Equipment:

_____ 1. Check that all accessory equipment - tools, lights, special systems, spares, etc., - are on site and in working order. In testing lights, tests should be conducted with lights submerged in water and extinguished before removal, to prevent overheating and failure.

_____ 2. Erect diving stage or attach diving ladder. In the case of the stage, ensure that the screw pin shackle connecting the stage line is securely fastened with the shackle pin seized with wire or a safety shackle is used to help prevent opening. Secure air-hose bulwark roller in place.

G. Preparing the Air Supply:

_____ 1. Check that a primary and suitable back-up supply is available with a capacity in terms of purity, volume, and supply pressure to completely service all divers, including decompression, recompressions, and accessory equipment throughout all phases of the planned operation.

_____ 2. Verify that all air supply systems have a suitable volume tank installed in the air supply line between the supply source and the diver's hose connection. An oil separator must be installed between the volume tank and the air source.

_____ 3. Ensure that qualified personnel are available to operate and stand watch on air supply.

4. Compressors:

___ a. Determine that sufficient fuel, coolant, lubricants, and anti-freeze are available to service all components throughout the operation. All compressors should be fully fueled, lubricated, and serviced (with all spillage cleaned up completely).

___ b. Verify that appropriate operating and service manuals are on hand.

___ c. Check maintenance and repair logs to ensure the suitability of the compressor (both primary and back-up) to support the operation.

___ d. Verify that all compressor controls are properly marked and any remote valving is tagged with "Divers Air Supply - Do Not Touch" signs.

Figure 4-20. Surface-Supplied Diving Operations Predive Checklist (sheet 2 of 5).

Surface-Supplied Diving Operations Checklist

(sheet 3 of 5)

___ e. Ensure that compressor is secure in diving craft and will not be subject to operating angles, caused by roll of pitch, that will exceed 15 degrees from the horizontal.

___ f. Verify that oil in the compressor is an approved type and is not petroleum-based. Check that the compressor oil does not overflow Fill mark; contamination of air supply could result from fumes or oil mist.

___ g. Check that compressor exhaust is vented away from work areas and, specifically, does not foul the compressor intake.

___ h. Check that compressor intake is obtaining a free and pure suction without contamination. Use pipe to lead intake to free suction if necessary.

___ i. Check that compressors are covered during operation.

___ j. Check all filters, cleaners, and oil separators for cleanliness.

___ k. Bleed off all condensed moisture from filters and from the bottom of volume tanks. Check all manifold drain plugs.

___ l. Check that all petcocks are closed.

___ m. Check that all belt-guards are properly in place on drive units.

___ n. Check all pressure-release valves, check valves, and automatic unloaders. Ensure that wing nut on unloader is in the compressing position.

___ o. Verify that all supply hoses running to and from compressor have proper leads, do not pass near high-heat areas such as steam lines, are free of kinks and bends, and are not exposed on deck in such a way that they could be rolled over, damaged, or severed by machinery or other means.

___ p. Verify that all pressure supply and interface hoses have safety lines and strain reliefs properly attached.

H. Activate the Air Supply:

___ 1. Compressors:

___ a. Ensure that all warm-up procedures are completely followed.

___ b. Check all petcocks, filler valves, filler caps, overflow points, bleed valves, and drain plugs for leakage or malfunction of any kind.

___ c. Soap-test all valves and connections.

___ d. Verify that there is a properly functioning pressure gauge on the air receiver and the compressor is meeting its delivery requirements.

___ e. In all cases where compressors are used as a back-up, either to a shipboard system, cylinder bank or another compressor, the back-up compressor will be kept running throughout the diving operation.

Figure 4-20. Surface-Supplied Diving Operations Predive Checklist (sheet 3 of 5).

Surface-Supplied Diving Operations Checklist

(sheet 4 of 5)

___ 2. Cylinders:

- ___ a. Gauge all cylinders for proper pressure.
- ___ b. Verify availability and suitability of reserve cylinders.
- ___ c. Check all manifolding and valving for operation.
- ___ d. Activate and check delivery.

___ 3. For all supply systems, double check "Do Not Touch" tags (tag outs).

I. Air Hoses:

___ 1. Ensure all hoses have a clear lead and are protected from excessive heating and damage.

___ 2. Check hose maximum shelf life.

___ 3. Ensure that the hose (or any length) has not been used in a burst test program. No hose length involved in such a program may be part of an operational hose.

___ 4. Check that hoses are free of moisture, packing material, or chalk.

___ 5. Soap test hose conections after connection to air supply and pressurization.

___ 6. Check that newest (or best) hose length is nearest the surface, where the hose will be subjected to greatest pressure change.

___ 7. Check that all tie-offs, and the canvas chafing over the first length of hose, are iin good condition.

___ 8. If possible, check gaskets at hose-length connections.

J. Test of Equipment with Activated Air Supply:

___ 1. Hook up all air hoses to helmets, masks, and chamber; make connections between back-up supply and primary supply manifold.

___ 2. Verify flow to helmets and masks.

___ 3. Check all exhaust and non-return valves.

___ 4. Hook up and test all communications.

___ 5. Check air flow from both primary and back-up supplies to chamber.

Figure 4-20. Surface-Supplied Diving Operations Predive Checklist (sheet 4 of 5).

Surface-Supplied Diving Operations Checklist

(sheet 5 of 5)

K. Recompression Chamber Checkout (Predive only):

____ 1. Check that chamber is completely free and clear of all combustible materials.

____ 2. Check primary and back-up air supply to chamber and all pressure gauges.

____ 3. Check that chamber is free of all odors or other contaminants.

____ 4. Hook up and test all communications.

____ 5. Check air flow from both primary and back-up supplies to chamber.

L. Final Preparations:

____ 1. Verify that all necessary records, logs, and timesheets are on the diving station.

____ 2. Check that appropriate decompression tables are readily at hand.

____ 3. Place the dressing bench in position, reasonably close to the diving ladder or stage, to minimize diver travel.

Figure 4-20. Surface-Supplied Diving Operations Predive Checklist (sheet 5 of 5).

Emergency Assistance Checklist

RECOMPRESSION CHAMBER	GAS SUPPLIES
Location	Location
Name/Phone Number	Name/Phone Number
Response Time	Response Time
AIR TRANSPORTATION	**COMMUNICATIONS**
Location	Location
Name/Phone Number	Name/Phone Number
Response Time	Response Time
SEA TRANSPORTATION	**DIVING UNITS**
Location	Location
Name/Phone Number	Name/Phone Number
Response Time	Response Time
HOSPITAL	**COMMAND**
Location	Location
Name/Phone Number	Name/Phone Number
Response Time	Response Time
DIVING MEDICAL OFFICER	**EMERGENCY CONSULTATION**
Location	
Name/Phone Number	
Response Time	

EMERGENCY CONSULTATION
Duty Phone Numbers 24 Hours a Day

Navy Experimental Dive Unit (NEDU)

Commercial	(904) 234-4351
	(904) 235-1668
Autovon	436-4351

Naval Medical Research Institute (NMRI)

Commercial	(301) 295-1839
Autovon	295-1839

Figure 4-21. Emergency Assistance Checklist.

exertion are the greatest dangers to the trapped diver. If the situation cannot be resolved readily, help should be obtained. A new umbilical can be provided to the surface-supplied diver; the SCUBA diver can be given a new apparatus or can be furnished air by the dive partner.

Once the diver has been freed and returns to the surface, the diver must be examined and treated, bearing in mind the following considerations.

- The diver will probably be overtired and emotionally exhausted.
- The diver may be suffering from or approaching hypothermia.
- The diver may have a physical injury.
- A SCUBA diver may be suffering from asphyxia. If a free ascent has been made, gas embolism may have developed.
- Significant decompression time may have been missed.

4-10.5.3 Equipment Failure. With well maintained equipment that is thoroughly inspected and tested before each dive, operational failure will rarely be a problem. When a failure does occur, the correct procedures will depend upon the type of equipment and dive. As with most emergencies, the training and experience of the diver and the diving team will be the most important factor in resolving the situation safely.

4-10.5.4 Loss of Gas Supply. Usually, when a diver loses breathing gas it will be obvious immediately. Surface-supplied, open-circuit breathing gear may have a small amount of gas trapped in the diving dress which may supply a few minutes of gas. Other diving apparatus may have an emergency gas supply (EGS). When breathing gas is interrupted, the dive must be aborted and the diver surfaced as soon as possible. Surfacing divers may be suffering from hypoxia, hypercapnia, missed decompression, or a combination of the three and should be treated accordingly.

4-10.5.5 Loss of Communications. If audio communications are lost with surface-supplied gear, the system may have failed or the diver could be in trouble. If communications are lost:

(1) Use line-pull signals at once. Depth, current, bottom or work site conditions may interfere.

(2) Check the rising bubbles of air. A cessation or marked decrease of bubbles could be a sign of trouble.

(3) Listen for sounds from the diving helmet. If no sounds are heard, the circuit is probably out of order. If the flow of bubbles seems normal, the diver may be all right.

(4) If sounds are heard and the diver does not respond to signals, assume the diver is in trouble.

(5) Have divers already on the bottom investigate, or send down the standby diver to do so.

4-10.5.6 Lost Diver. In planning for an operation using SCUBA, lost diver procedures must be included in the dive plan and dive brief. Loss of contact with a SCUBA diver can be the first sign of a serious problem. If contact between divers is lost, each diver should surface. If the diver is not located quickly, or found at the surface (following correct lost communications procedure), the Diving Supervisor must initiate search procedures immediately. At the same time, medical personnel should be notified and the recompression chamber team alerted.

Difficulty in locating and assisting a trapped or injured diver increases greatly when visibility is poor.

A lost diver is often disoriented and confused, and may have left the operating area. Nitrogen narcosis or other complications involving the breathing mixture, which can result in confusion, dizziness, anxiety, or panic, are common in recovered lost divers. The diver may harm the rescuers unknowingly. When the diver is located, the rescuer should approach with caution to prevent being harmed, and briefly analyze the stricken diver's condition.

If the diver is found unconscious, attempts should be made to resupply breathing gas and restore consciousness. If this cannot be accomplished, the diver must be brought to the surface immediately. Significant decompression may be missed and immediate recompression may be required to keep the diver alive. If it is possible to provide the diver with an air supply (such as a single-hose demand SCUBA), the rescuer should do so during the ascent.

4-10.6 Debriefing the Diving Team. After the day's diving has been completed (or after a shift has finished work if the operation is being carried on around the clock) all members of the diving team should be brought together for a short debriefing of the day's activities. This offers all personnel a chance to provide feedback to the Diving Supervisor and other members of the team. This group interaction can be of great help in clarifying any confusion which may have arisen because of faulty communications, lack of dive site information, or misunderstandings from the initial briefing.

4-11 RECORD KEEPING

Records should provide an accurate and detailed account of a diving operation, and a tabulation of supplies expended to support the operation. The Diving Officer, Master Diver, and Diving Supervisor should identify those records required for the unit's diving systems and tailor them to suit organizational needs. Any unusual circumstances regarding the dive (i.e., treatments, Operational/Emergency Procedures, or deviation from procedures as established in the *U.S. Navy Diving Manual*) must be brought to the attention of the Commanding Officer and logged in the Command Smooth Diving Log.

4-11.1 Command Smooth Diving Log. The Command Smooth Diving Log is the official chronological record of procedures and events for an entire dive. It is mandatory that all U.S. Navy diving activities maintain a Command Smooth Diving Log. The log shall be legibly maintained in a narrative style. The Diving Officer, Master Diver, and Diving Supervisor shall review and sign the log daily or at the end of their watches. The Command Smooth Diving Log must be retained for three years after the date of the dive.

4-11.2 Operating Procedures. Operating Procedures (OPs) are detailed checksheets for operating the diving system and for performing various system-related tasks. Approved Operating Procedure checksheets are required by the *U.S. Navy Diving and Manned Hyperbaric Systems Safety Certification Manual* (SS521-AA-MAN-010) for all U.S. Navy diving activities. The checksheets must be signed by the operator, Diving Officer, Master Diver, and Diving Supervisor. The completed check sheets shall remain on file until the dive is completed. If an accident or casualty occurs, the Operating Procedures checksheets will be retained indefinitely and may become part of the official investigation records. See Appendix N.

4-11.3 Emergency Procedures. Emergency Procedures (EPs) are detailed instructions for handling system or procedural failures (loss of diver's gas, fouled umbilical, etc.). All members of the diving team/watch section shall be qualified and must be thoroughly drilled periodically in all Emergency Procedures. The approved

Emergency Procedures are required by the *U.S. Navy Diving and Manned Hyperbaric Systems Safety Certification Manual* to be on board during all U.S. Navy diving operations. See Appendix N.

4-11.4 Daily Predive Checksheets. Daily predive checksheets are used for recording diving equipment used, temperature readings, gas pressures, gas usage, machinery used, etc. They will be reviewed and signed by the Diving Officer and Diving Supervisor. Any discrepancies are logged in the Command Smooth Diving Log. Daily predive checksheets will be retained until the diving operation is completed. Should an accident or casualty occur, the predive checksheets will be retained indefinitely and may become part of the official investigation records.

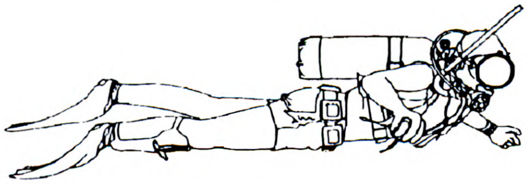
4-11.5 Dive Log (DD2544). Appendix E of this manual provides information about the Diving Log (DD2544). OPNAVINST 3150.2 presents guidance for the proper completion of the report form. It is each diver's responsibility to complete and submit a DD2544 report for each dive or hyperbaric exposure. A copy of the signed original should be retained for the diver's personal record.

4-11.6 Equipment Failure Analysis Report (FAR). Appendix E of this manual provides information about NAVSEA form 10560/4, the Diving Life Support Equipment FAR form. The FAR contributes to diving safety and the timely resolution of problems with diver life support equipment through a rapid response reporting system.

4-12 AIR DIVING EQUIPMENT REFERENCE DATA

Figures 4-22 through 4-25 illustrate the capabilities and logistical requirements of air diving systems including SCUBA, MK 20 MOD 0, MK 21, and the MK 12 Surface-Supplied Diving System.

SCUBA General Characteristics



- **Principle of Operation**
  Self-contained, open-circuit demand system

- **Minimum Equipment**
  Open-circuit SCUBA
  Life preserver
  Weight belt
  Dive knife
  Face mask
  Swim fins
  Submersible wrist watch
  Submersible depth gage

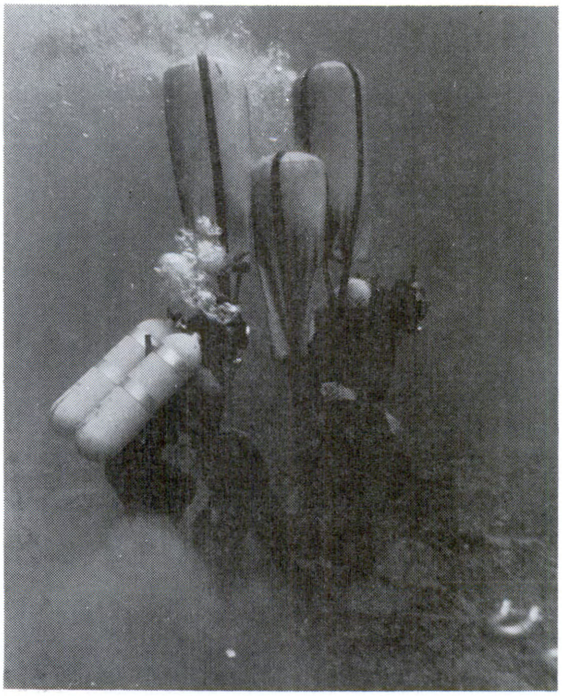
- **Principal Applications**
  Shallow water search
  Inspection
  Light repair and recovery

- **Advantages**
  Rapid deployment
  Portability
  Minimum support requirements
  Excellent horizontal and vertical mobility
  Minimum bottom disturbances

- **Disadvantages**
  Limited endurance (depth and duration)
  Relatively high breathing resistance
  Limited physical protection
  Influenced by current
  Lack of voice communication (unless equipped with a through-water communications system)

- **Restrictions**
  Work limits:
    Normal 130 fsw
    Maximum 190 fsw, with Commanding Officer's Permission
    100 fsw with single SCUBA bottle, twin bottles required below 100 fsw
  Within no-decompression limits
  Current - 1 knot maximum
  Diving team - minimum 4 persons

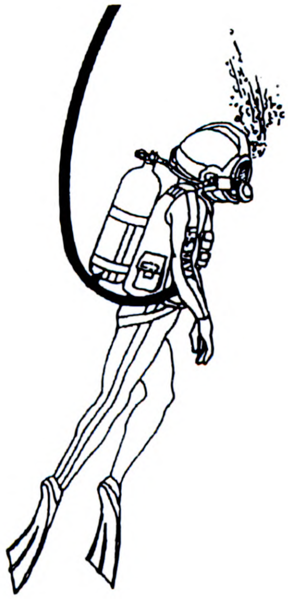
- **Operational Considerations**
  Standby diver required.
  Small craft mandatory for diver recovery during open ocean diving.
  Moderate to good visibility preferred.
  Ability to free ascend to surface required (see paragraph 5-4.7.2).



Open-Circuit SCUBA Divers at Work.

Figure 4-22. SCUBA General Characteristics.

MK 21 MOD 1 General Characteristics



- **Principle of Operation**
  Surface-supplied, open-circuit lightweight system

- **Minimum Equipment**
  MK 21 MOD 0 Helmet
  Harness
  Weight belt
  Dive knife
  Swim fins or shoes
  Surface umbilical

- **Principle Applications**
  Shallow water search
  Inspection and light salvage
  Major ship repair

- **Advantages**
  Unlimited by air supply
  Good horizontal mobility
  Voice and/or line pull communications capabilities
  Fast deployment

- **Disadvantages**
  Limited physical protection
  Limited vertical mobility
  Large support craft required

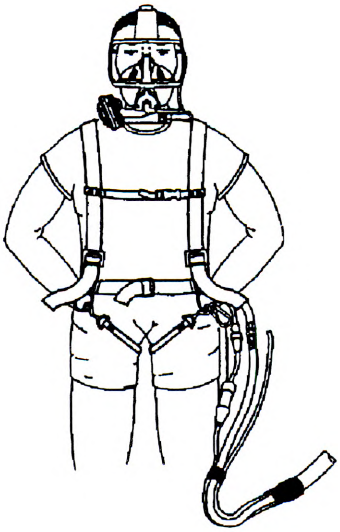
- **Restrictions**
  Work limits: 190 fsw
  Current - 2.5 knots maximum with extra weights

- **Operational Considerations**
  Adequate air supply system required
  Standby diver required

MK 21 MOD 1 Helmet.

Figure 4-23. MK 21 MOD 1 General Characteristics.

MK 20 MOD 0 General Characteristics



- **Restrictions**
  Work limits: 60 fsw
  Current - 2.5 knots maximum with extra weights
  Enclosed space diving requires an Emergency Gas Supply (EGS) with 150-foot whip and second stage regulator

- **Operational Considerations**
  Adequate air supply system required
  Standby diver and underwater tender required when diving in an enclosed space.

- **Principle of Operation**
  Surface-supplied, open-circuit lightweight system

- **Minimum Equipment**
  MK 20 MOD 0 mask, harness and manifold
  Weight belt
  Dive knife
  Swim fins or shoes
  Surface umbilical

- **Principle Applications**
  Diving in mud tanks and enclosed spaces

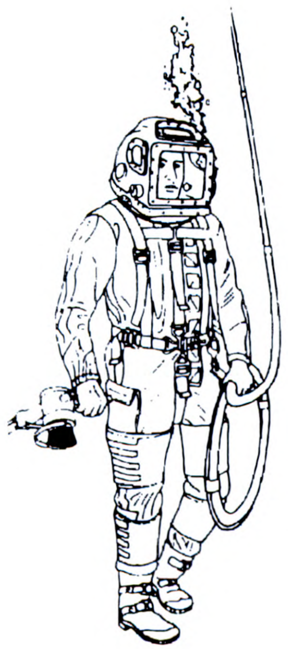
- **Advantages**
  Unlimited by air supply
  Good horizontal mobility
  Voice and/or line pull communications capabilities

- **Disadvantages**
  Limited physical protection
  Limited vertical mobility
  Large support craft required

MK 20 MOD 0 Mask.

Figure 4-24. MK 20 MOD 0 General Characteristics.

MK 12 General Characteristics



- **Principle of Operation**
  Surface-supplied, open-circuit system

- **Minimum Equipment, Task Dependent, Normal Configuration**
  Helmet assembly
  Dry suit with lower breech ring
  Outer garmet
  Thermal underwear
  Jocking harness
  Leg weights
  Hip weights
  Boots
  Surface umbilical

- **Minimum Equipment, Swimming Configuration**
  Helmet Assembly
  Lower breech ring
  Jocking harness (undershirt recommended to prevent chafing)
  Swim fins
  Weight belt
  Surface umbilical

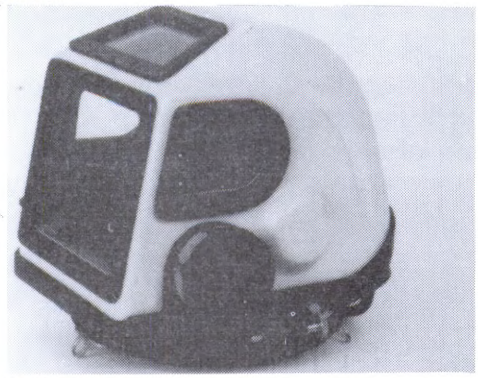
- **Principle Applications**
  Deep diving operations
  Heavy salvage and repair
  Underwater construction

- **Advantages**
  Unlimited by air supply
  Maximum physical and thermal protection
  Voice and/or line pull communications capabilities
  Variable buoyancy capability

- **Disadvantages**
  Large support craft and surface crew required

- **Restrictions**
  Work limits:
    Normal - 190 fsw, Standard Air Decompression Table and Surface Decompression Table Using Air
    Maximum - 285 fsw (exceptional exposure)
  Current - 2.5 knots maximum with extra weights

- **Operational Considerations**
  Adequate air supply system required
  Standby diver required.
  Medical Officer and recompression chamber required below 190 feet.
  Planned exceptional exposures require approval of Chief of Naval Operations.



MK 12 Helmet Assembly.

Figure 4-25. MK 12 General Characteristics.

CHAPTER FIVE

AIR DIVING OPERATIONS (SCUBA)

5-1 INTRODUCTION

A general description of Self-Contained Underwater Breathing Apparatus (SCUBA) is presented in Chapter 4, along with a brief narrative covering the specific types of apparatus. Factors governing the use of SCUBA and various planning considerations are covered in Chapter 4, Operations Planning.

Of the three basic types of SCUBA (open-circuit, closed-circuit, and semiclosed-circuit), usually only open-circuit uses compressed air as the breathing medium. Use of open-circuit SCUBA (normally deployed in operations not requiring decompression) is covered in detail in this chapter. Decompression diving using open-circuit air SCUBA may be undertaken only if no other option exists and only with the concurrence of the Commanding Officer or Officer-in-Charge (OIC). Closed-circuit underwater breathing apparatus is the preferred method of performing SCUBA decompression dives. Operation of open-circuit, closed-circuit, and semiclosed-circuit systems designed for use with mixed-gas or oxygen is covered in Volume 2 of this manual. This Chapter covers:

- SCUBA equipment and accessories
- Predive procedures
- SCUBA communications
- SCUBA diving technique
- Safety precautions
- Postdive procedures, including field maintenance, stowage of equipment, and reporting

5-2 EQUIPMENT FOR SCUBA OPERATIONS

The minimum required equipment for each diver for the safe conduct of every open-circuit SCUBA dive is pictured in Figure 5-1.

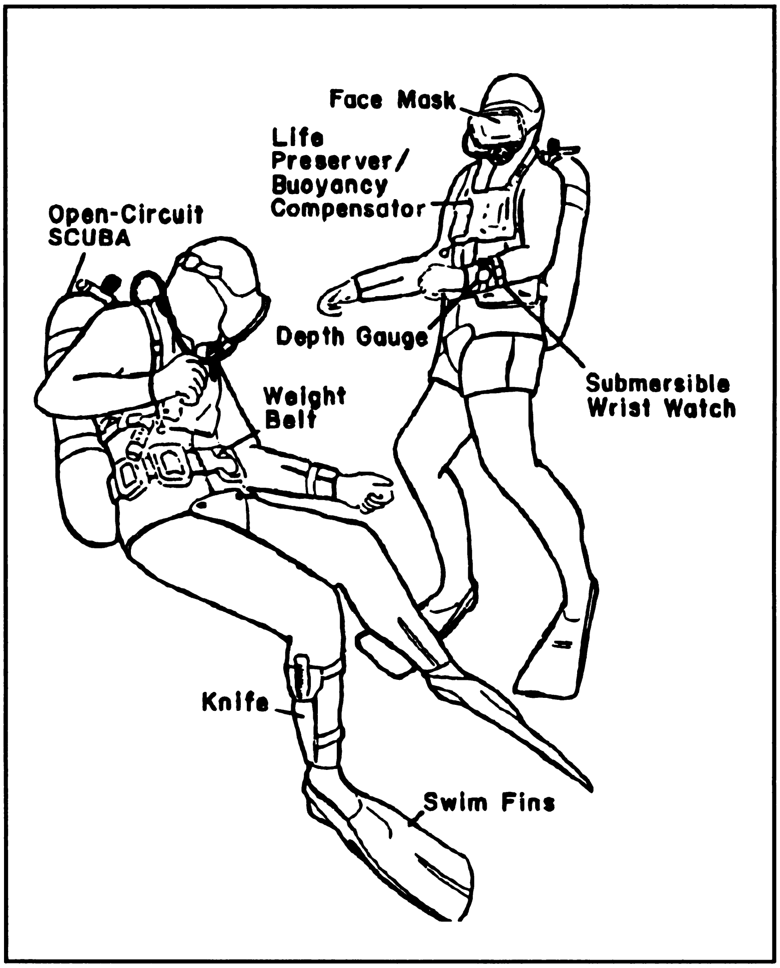


Figure 5-1. SCUBA Diver With Minimum Equipment.

This consists of:

- Open-circuit SCUBA
- Face mask
- * Life preserver/buoyancy compensator
- ** Weight belt and weights as required
- ** Knife
- Swim fins
- ** Submersible wrist watch
- ** Depth gauge

* during the problem solving pool phase of SCUBA training, CO_2 cartridges may be removed and replaced with plugs or expended cartridges that are painted international orange.

** item is not required for pool phase of SCUBA training.

If diving with nonmagnetic SCUBA in an operational Explosive Ordnance Disposal (EOD) dive when a low magnetic signature is required and a buddy line is used, only one depth gauge and one wrist watch per dive team are required. Additional equipment, such as cameras and lift bags, may be required for specific missions. All equipment must be authorized by the Commander, Naval Sea Systems Command, as specified in NAVSEA Instruction 10560.2 (series), Diving Equipment Authorized for Navy Use (see Paragraph 4-7.1.). A current copy of this instruction must be maintained by all diving activities.

5-2.1 Open-circuit SCUBA. All open-circuit SCUBA authorized for Navy use employ a demand system that supplies air each time the diver inhales. Open-circuit SCUBA includes the following basic components:

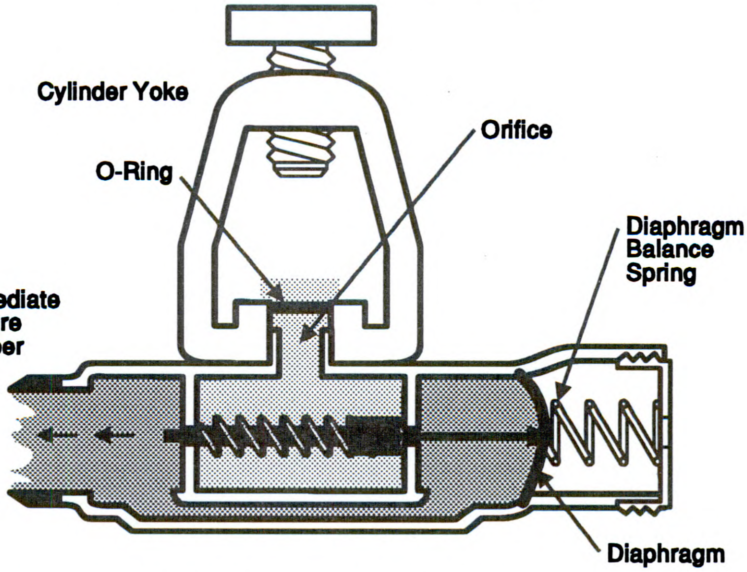
- Demand regulator assembly
- One or more air cylinders
- Cylinder J valve or K valve when regulator is equipped with submersiable bottle gauge and manifold assemblies
- Backpack or harness.

5-2.1.1 Demand Regulator Assembly.
The demand regulator assembly is the central component of the open-circuit system. The regulator delivers air to the diver after reducing the high-pressure air in the cylinder to a pressure that can be used by the diver.

There are two stages in a typical system (Figure 5-2). In the regulator's first stage, high-pressure air from the cylinder passes through a regulator which reduces the pressure of the air to a predetermined level over ambient pressure (refer to the regulator technical manual for the specific setting).

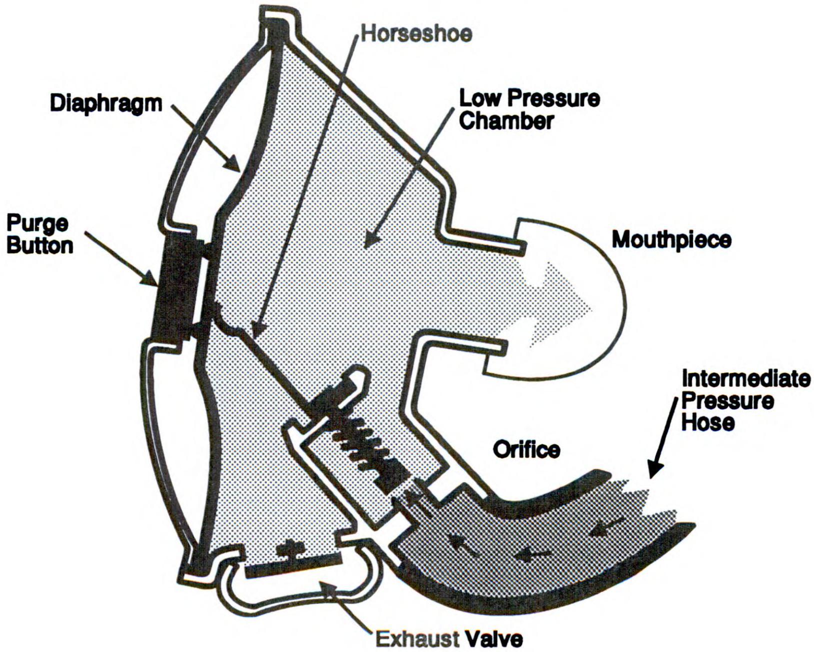
In the second stage of a regulator, a movable diaphragm is linked by a lever to the low-pressure valve, which leads to a low-pressure chamber. When the air pressure in the low-pressure chamber equals the ambient water pressure, the diaphragm is in the center position and the low-pressure valve is closed. When the diver inhales, the pressure in the low pressure chamber is reduced, causing the diaphragm to be pushed inward by the now higher ambient water pressure. The diaphragm actuates the low-pressure valve which opens, permitting air to flow to the diver. The greater the demand, the wider the low-pressure valve is opened, thus allowing more air flow to the diver. When the diver stops inhaling, the pressure on either side of the diaphragm is again balanced and the low-pressure valve closes. As the diver exhales, the exhausted

First Stage Valve Assembly



First Stage High pressure air flows through the orfice of the first stage into the intermediate chamber. When the pressure in the intermediate chamber reaches ambient plus diaphragm balance spring set pressure, the first stge valve assembly closes.

Second Stage Valve Assembly



Second Stage Upon inhalation the second stage diaphragm moves inward and the horseshoe lever opens the second stage valve assembly. Intermediate pressure air from the hoses is throttled across the orfice and fills the low pressure chamber to ambient pressure and flow is provided to the diver. Upon exhalation the diaphragm is pushed outward and the second stage valve is closed. Expired air is dumped from the low pressure chamber to the surrounding water through the exhaust valve.

Figure 5-2. Schematic of Demand Regulator.

air passes through at least one check valve and vents to the water.

5-2.1.1.1 Single-Hose Regulators. In the single-hose, two-stage demand regulator the first stage is mounted on the cylinder valve assembly. The second-stage assembly includes the mouthpiece and a valve to exhaust exhaled air directly into the water. The two stages are connected by a length of low-pressure hose, which passes over the diver's right shoulder. The second stage has a purge button, which when activated allows low-pressure air to flow through the regulator and the mouthpiece, forcing out any water which may have entered the system. Buddy breathing (a diver providing air from the SCUBA to a partner) is more easily accomplished with the single-hose regulator. Use of an additional second stage regulator "octopus" which is listed in NAVSEAINST 10560 (series) is an alternative and preferred method to accomplish "buddy breathing". The principal disadvantages of the single-hose unit are an increased tendency to freeze up in very cold water and the exhaust of air in front of the diver's mask. While the Navy PMS system provides guidance for repair and maintenance of SCUBA regulators, the manufacturers service manual should be followed for specific procedures.

The MK 20 MOD 0 mask may be used with an approved single-hose first-stage regulator, with an octopus, to the maximum approved depth of the regulator, as indicated in NAVSEAINST 10560.2 (series).

5-2.1.1.2 Mouthpiece. The size and design of SCUBA mouthpieces differ between manufacturers, but each mouthpiece provides relatively watertight passageways for delivering breathing air into the diver's mouth. The mouthpiece should fit comfortably with slight pressure from the lips. Divers should avoid biting down on the mouthpiece and severing the material as inexperienced divers tend to do.

5-2.1.2 Cylinders. SCUBA cylinders (tanks or bottles) are designed to hold compressed air at pressures of 2,250 psig for steel cylinders, and 3,000 psig for aluminum cylinders. Because of the extreme stresses imposed on a cylinder at these pressures, all cylinders used in SCUBA diving must be inspected and tested periodically. Seamless steel or aluminum cylinders which meet Department of Transportation (DOT) specifications (DOT 3AA, DOT 3AL, DOT SP6498, and DOT E6498) are approved for Navy use. Each cylinder used in Navy operations must have identification symbols stamped into the shoulder (Figure 5-3).

Approved SCUBA cylinders are available in several sizes, and one or two cylinders may be worn to provide the required quantity of air for the dive. The volume of a cylinder, expressed in actual cubic feet or cubic inches, is a measurement of the internal volume of the cylinder. The capacity of a cylinder, expressed in standard cubic feet or liters, is the amount of gas (measured at surface conditions) that the cylinder holds when charged to its rated pressure. Table 5-1 lists the sizes of some standard SCUBA cylinders. For approved SCUBA cylinders, refer to NAVSEAINST 10560.2 (series).

Nonmagnetic (aluminum) cylinders manufactured under special Navy contract for use by Explosive Ordnance Disposal teams will not bear DOT (formerly ICC) markings. These aluminum cylinders can be used in either single or double tank configuration. Steel and aluminum cylinders procured from commercial sources outside normal Navy supply channels may not have any special Navy markings. These cylinders must meet DOT requirements. Always refer to the cylinder and/or valve manufacturers service manual for maintenance, repair procedures, and specifications when servicing this equipment.

5-2.1.2.1 Inspection and Handling.
Open-circuit SCUBA cylinders must be visu-

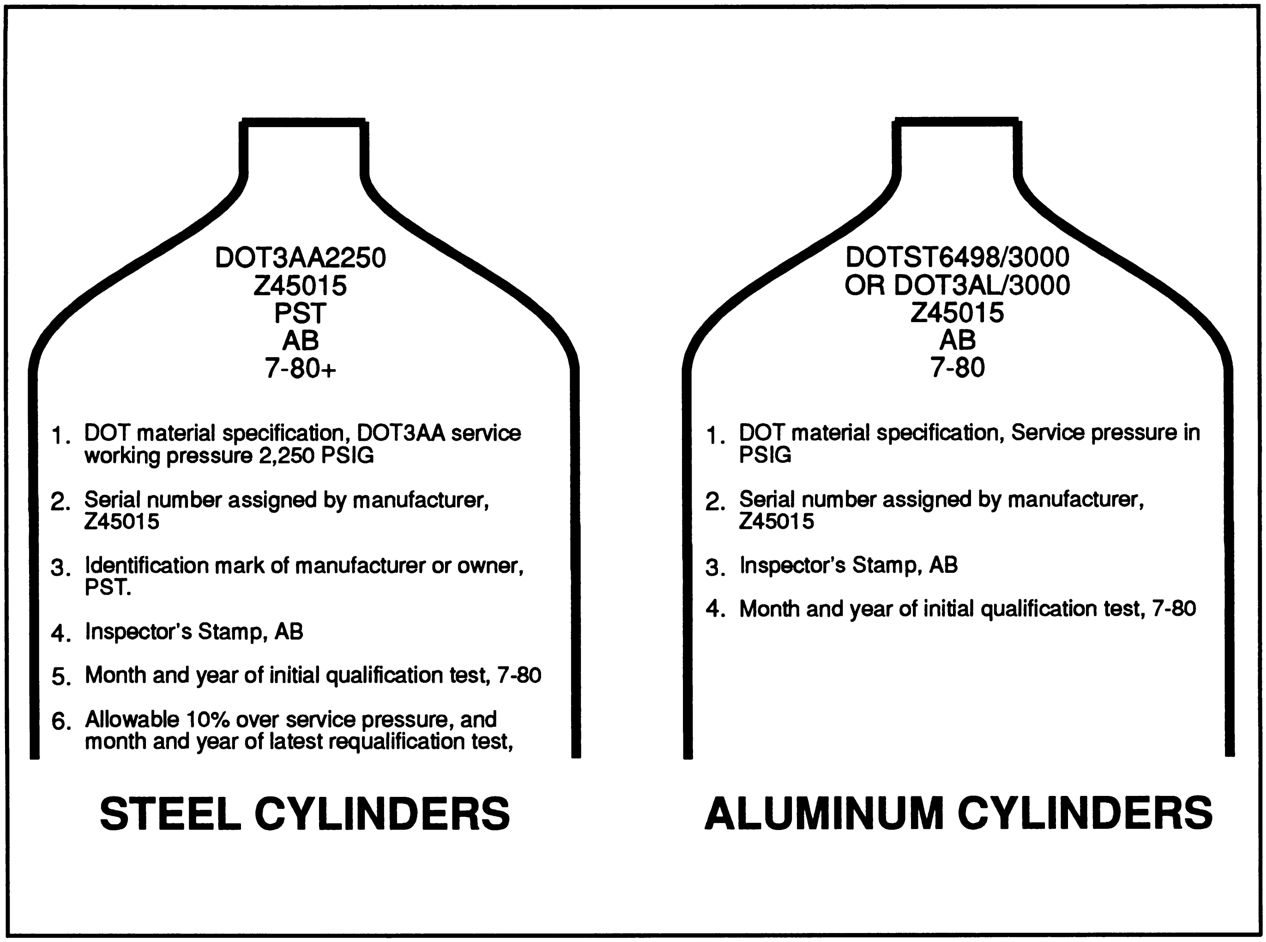


Figure 5-3. Typical Gas Cylinder Identification Markings.

Table 5-1. Sample SCUBA Cylinder Data.

Open-Circuit Cylinder Description (Note 1)	Rated Working Pressure (PSIG)	Internal Volume (Cu. Ft.)	Absolute Air Capacity At Rated Pressure (Cu. Ft.)	Reserve Pressure (PSIG)	Outside Dimensions (Inches)	
					(Dia)	(Length)
Steel 72	2,250	0.420	64.7	500	6.80	25.00
Aluminum 50	3,000	0.281	48.5	500	6.89	19.00
Aluminum 63	3,000	0.319	65.5	500	7.25	21.75
Aluminum 80	3,000	0.399	81.85	500	7.25	26.00
Note 1:	Fifty cubic feet is the minimum size SCUBA cylinder authorized. SEAL teams are authorized smaller cylinders for special operations.					

ally inspected at least once every 12 months and every time water or particulate matter is suspected in the cylinder. Cylinders containing visible accumulations of corrosion must be cleaned before being placed into service. Commercially available steel and aluminum SCUBA cylinders, as specified in NAVSEA Instruction 10560.2 (series), which meet DOT specifications, as well as SCUBA cylinders designed to Navy specifications, must be visually inspected at least annually and must be hydrostatically tested at least every five years in accordance with DOT regulations and Compressed Gas Association (CGA) pamphlets C-1 and C-6. Special Navy non-magnetic EOD aluminum cylinders (non-DOT) are to be hydrostatically tested at least every three years.

General safety regulations governing the handling and use of compressed gas cylinders aboard Navy ships are contained in NAVSEA 0901-LP-230-0002, NSTM Chapter 550. Persons responsible for handling, storing, and charging SCUBA cylinders must be familiar with these regulations. Safety rules applying to SCUBA cylinders are contained in Paragraph 5-3.5. Because SCUBA cylinders are subject to continuous handling and because of the hazards posed by a damaged unit, close adherence to the rules is mandatory.

5-2.1.2.2 Cylinder Valves and Manifold Assemblies. Cylinder valves and manifolds make up the system that passes the high-pressure air from the cylinders to the first-stage regulator. The cylinder valve serves as an on/off valve and is sealed to the tank by a straight-threaded male connection containing a neoprene O-ring on the valve's body. New 72-cubic-foot steel cylinders and all aluminum cylinders have 3/4-inch straight threads, while older cylinders have 1/2-inch pipe threads.

The cylinder valve contains a high-pressure blowout plug or safety disc plug in the event of excessive pressure buildup (Table 5-2). When a dual manifold is used, two blowout plugs or safety disc plugs are installed. Commercial DOT approved steel cylinders rated at 2,250 psig use 3,750-psig plugs and aluminum cylinders rated at 3,000 psig use 5,000-psig plugs. The plug rating is stamped on the face of the plug, and may be used only with the appropriate cylinders. Special nonmagnetic EOD aluminum cylinders not approved by DOT use a 3,712-psig blowout plug.

For diving operations requiring nonmagnetic diving equipment, only fusible blowout plugs should be used. Do not install a safety disc in conjunction with a fusible blowout plug.

For standard diving equipment, a safety disc plug similar to new issue equipment is recommended. The safety disc plug and safety disc are not always identified by a National Stock Number (NSN), but are available commercially.

If two or more cylinders are to be used together, a manifold unit is needed to provide the necessary interconnection (Figure 5-4). Most manifolds incorporate an O-ring as a seal, but some earlier models may have a tapered (pipe) thread design. One type will not connect with the other type.

A cylinder valve with an air reserve (J valve) is preferred. When a cylinder valve without an air reserve (K valve) is used, the SCUBA regulator must be equipped with a submersible pressure gauge to indicate pressure contents of the cylinder. The dive must be terminated when the cylinder pressure reaches 500 psi for a single cylinder or 250 psi for twin manifold cylinders. The air reserve mechanism: (1) alerts the diver that the available air supply is almost exhausted and (2) provides the diver with a reserve of air sufficient to reach the surface. The air reserve mechanism contains a spring-loaded check valve. Whenever a diver finds it increasingly difficult to obtain a full breath, the diver must reach over the left shoulder and push down the

Table 5-2. Blowout Disc/Plug Pressure Limits.

Manufacturer	Blowout Pressure		Identification Mark		Part Number	
	(Working) 2250 PSIG	(Working) 3000 PSIG	2250	3000	2250	3000
DACOR	3375-3750	4500-5000	35 On Plug	48 On Plug	KV-35 Comes As A Kit	KV-48 Comes As A Kit
U.S. Divers	2900-3300	3750-4500	3750 B On Plug Black Disc	5000 R On Plug Red Disc	0502-42	0502-41
Sherwood	3500	4800	35 On Plug	48 On Plug	1-4000-120-35 Comes As A Kit	1-4000-120-48 Comes As A Kit
Parkway		4800		48 On Plug		T-3000-SP Comes As A Kit

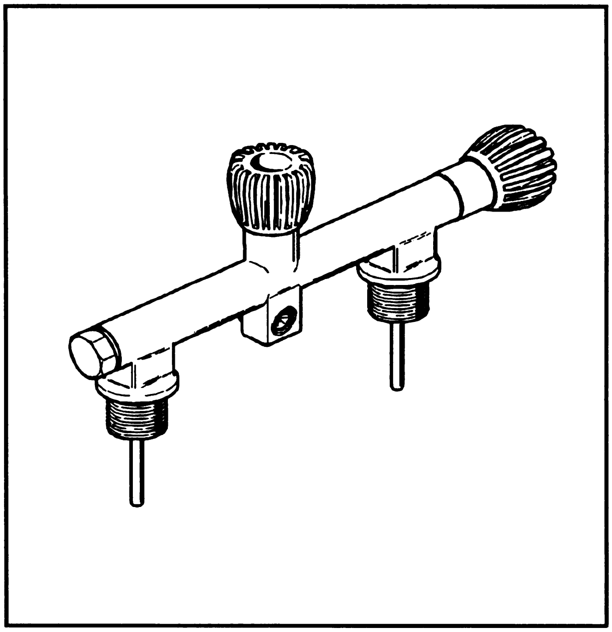


Figure 5-4. High Pressure Manifold.

reserve lever, opening the reserve valve to make the remaining air available.

Dive planning should not extend bottom time by including the use of reserve air. The diver should never assume that the reserve air supply will be provided. When the resistance to breathing becomes obvious, the diver should notify the dive partner that the air supply is low and both should start for the surface immediately. **The dive must be terminated when either diver shifts to reserve air.**

5-2.1.3 Backpack or Harness. A variety of backpacks or harnesses, used for holding the SCUBA on the diver's back, have been approved for Navy use. The backpack may include a lightweight frame with the cylinder(s) held in place with clamps or straps. The usual system for securing the cylinder to the diver uses shoulder and waist straps. All straps must have a quick-release feature, easily operated by either hand, so that the cylinder can be removed and left behind in an emergency (Figure 5-5).

5-2.2 Minimum Equipment.

5-2.2.1 Face Mask. The face mask protects the diver's eyes and nose from the water. Addition-

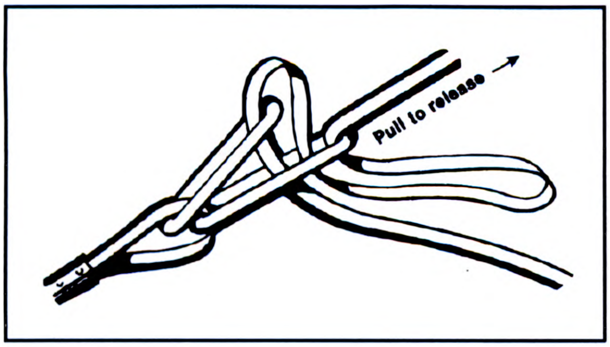


Figure 5-5. Accepted Quick-Release Cylinder Harness Tie Method.

ally, it provides maximum visibility by putting a layer of air between the diver's eyes and the water.

Face masks are available in a variety of shapes and sizes for diver comfort. To check for proper fit, hold the mask in place with one hand and inhale gently through the nose. The suction produced should hold the mask in place. Don the mask with the head strap properly adjusted, and inhale gently through the nose. If the mask seals, it should provide a good seal in the water.

Some masks are equipped with a one-way purge valve to aid in clearing the mask of water. Some masks have indentations at the nose or a neoprene nose pad to allow the diver to block the nostrils to equalize the pressure in the ears and sinuses. Several models are available for divers who wear eyeglasses. One type provides a prescription-ground faceplate, while another type has special holders for separate lenses. All faceplates must be constructed of tempered or shatterproof safety glass because faceplates made of ordinary glass can be hazardous. Plastic faceplates are generally unsuitable as they fog too easily and are easily scratched.

The size or shape of the faceplate is a matter of personal choice, but the diver should use a mask which provides a wide, clear range of vision.

5-2.2.2 Life Preserver. A Navy-approved life preserver must be worn by Navy SCUBA divers (except when diving under the ice as explained in Appendix J). The principal functions of the life preserver are to assist a diver in rising to the surface in an emergency and to keep the diver on the surface in a head-up position (Figure 5-6). The low-pressure inflation device on the preserver may be actuated by the diver, or by a dive partner should the diver be unconscious or otherwise incapacitated.

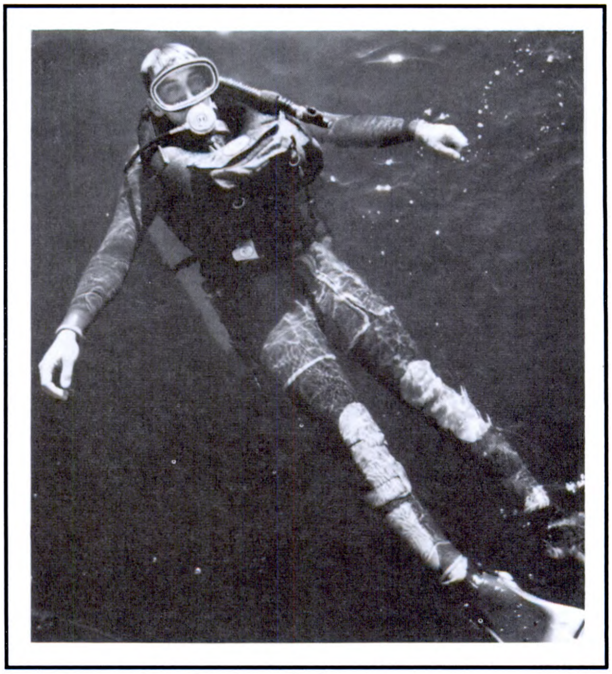


Figure 5-6. MK-4 Life Preserver.

All models used by the Navy must be authorized by NAVSEAINST 10560.2 (series) and have a manual inflation device in addition to the low-pressure inflation device (Table 5-3). With the exception of the UDT (9C-4220-00-276-8929), an overinflation valve or relief valve is required to ensure against possible rupture of the life preserver on ascent. Some ANU models are available commercially while others may be procured through the Navy supply system. In selecting a life preserver for a specific task, the individual technical manuals should be consulted.

The life preserver must be sturdy enough to

Table 5-3. U.S. Navy Life Preserver and Cartridge Specifications

Life Preserver Model	NSN	MIL-STD	No. and Wt. CO_2 Cartridge Required	Limitations
UDT	9C-4220-00-276-8929	MIL-L-16383	One 18-gram	33 fsw with open-circuit SCUBA
Modified UDT (Formerly RFI)	1H-4220-01-221-4012	MIL-L-16383	Two 31-gram	130 fsw with open-circuit SCUBA
MK-4	9C-4220-00-965-0595	MIL-C-16385 Type II (9C 4220-00-965-0595)	Four 31-gram	MK 15/16 SCUBA - 190 fsw
		MIL-C-25369 Type I (9C 4220-00-272-0585)	Four 25-gram	SCUBA - 190 fsw
		MIL-C-16385 Type I (9C 4220-00-287-3741)	Four 17-gram	SCUBA - 130 fsw

resist normal wear and tear, and of sufficient volume to raise an unconscious diver safely from maximum dive depth to the surface.

Most life preservers currently in use employ carbon dioxide (CO_2) cartridges to provide inflation in an emergency. The cartridges must be the proper size for the life preserver. Cartridges must be weighed upon receipt and prior to use, in accordance with the planned maintenance system (PMS) for the life preserver, to ensure the actual weight is in compliance with the weight tolerance for the cartridge cylinder. Carbon dioxide cartridges used with commercially available life preservers with low-pressure inflators do not have the weight stamped on the cartridge cylinder. The actual weight of these cartridges must be inscribed on the cartridge, and be within the tolerance for weight. The Soniform Pneumatic Inflator may be used to convert the life preserver to a buoyancy compensator.

5-2.2.3 Buoyancy Compensator. Buoyancy compensators have two functions: adjustment of diver buoyancy at depth to facilitate work requirements and to act as a life preserver. A list of approved bouyancy compensators is contained in NAVSEAINST 10560.2 (series). When selecting a buoyancy compensator, a number of factors must be considered. These factors include: type of wet suit, diving depth, breathing equipment characteristics, nature of diving activity, accessory equipment, and weight belt.

As a buoyancy compensating device, the compensator can be inflated by a low-pressure inflator connected to the first-stage regulator, or an oral inflation tube. Any buoyancy compensator selected for Navy use must have an over-pressure relief valve. The compensator is used in conjunction with the diver weights to control buoyancy in the water column by allowing the diver to increase displacement through inflation of the device, or to decrease displacement by venting. Training and practice under controlled conditions are required to master the buoyancy compensation technique. Rapid, excessive inflation can cause excessive buoyancy and uncontrolled ascent. The diver must systematically vent air from the compensator during ascent to maintain proper control.

As a life preserver, the buoyancy compensator must be designed so that a diver, even if unconscious, will float face up. Emergency inflation is provided by a compressed air cylinder, other than breathing source, or a CO_2 cartridge. Regardless of the method used for emergency inflation, the flotation device must have an oral inflation tube which has a large diameter and is capable of operation from either side of the diver. The well-designed buoyancy compensator should not ride above the head or choke the diver when inflated.

Refer to the appropriate technical manual for complete operations and maintenance instructions for the equipment.

5-2.2.4 Weight Belt. SCUBA is designed to have nearly neutral buoyancy. With full tanks, a unit tends to have negative buoyancy, becoming slightly positive as the air supply is consumed. Most divers are positively buoyant and need to add extra weight to achieve a neutral or slightly negative status. This extra weight is furnished by a weighted belt worn outside of all other equipment and strapped so that it can be easily released in the event of an emergency (Figure 5-7).

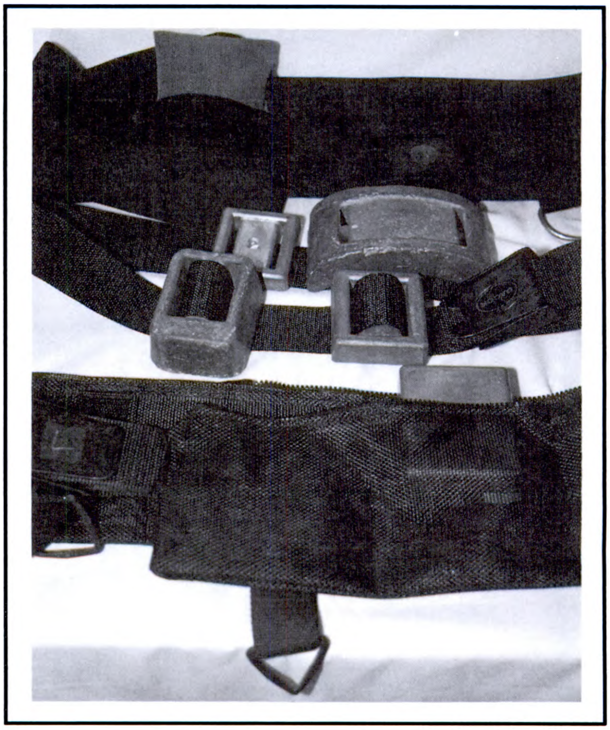


Figure 5-7. Typical Weight Belts with Quick-Release Buckles.

Each diver may select the style and size of belt and weights which best suit the diver. A number of different models are available. A weight belt shall meet certain basic standards: the buckle must have a quick-release feature, easily operated by either hand; the weights (normally made of lead) should have smooth edges so as not to chafe the diver's skin or damage any protective clothing; and the belt should be made of rot and mildew resistant fabric, such as nylon webbing.

5-2.2.5 Knife. Several types of knives are available. For EOD and other special missions, a nonmagnetic knife designed for use when diving near magnetic-influence mines is used.

Diving knives should have corrosion resistant blades and a handle of plastic, hard rubber, or wood. Handles made of wood should be waterproofed with paint, wax, or linseed oil. Handles of cork or bone should be avoided, as these materials deteriorate rapidly when subjected to constant saltwater immersion. Cork may also float the knife away from the diver.

Knives may have single- or double-edged blades with chisel or pointed tips. The most useful knife has one sharp edge and one saw-toothed edge. All knives must be kept sharp.

The knife must be carried in a suitable scabbard and worn on the diver's life preserver, hip, thigh, or calf. The knife must be readily accessible, must not interfere with body movement, and must be positioned so that it will not become fouled while swimming or working. The scabbard should hold the knife with a positive but easily released lock.

The knife and scabbard must not be secured to the weight belt. If the weights are released in an emergency, the knife may also be dropped unintentionally.

5-2.2.6 Swim Fins. Swim fins increase the efficiency of the diver, permitting faster swimming over longer ranges with less expenditure of energy. Swim fins are made of a variety of materials and styles. There are two basic types: straight blade and offset blade. The straight blade directly extends the line of the foot, while the offset blade is set at an angle. The offset style places the blade in a nearly horizontal position as the swimmer moves through the water. Both types are satisfactory, although the straight blade, which requires a greater extension of the foot, tends to cause leg cramps sooner than the offset blade.

Each feature - flexibility, blade size, and configuration - contributes to the relative power of the fin. A large blade will transmit more power from the legs to the water, provided the legs are strong enough to use a larger blade. Small or soft blades should be avoided. Ultimately, selection of blade type is a matter of personal preference based on the diver's strength and experience.

5-2.2.7 Wrist Watch. Analog diver's watches must be waterproof, pressure-proof, and equipped with a rotating bezel outside the dial that can be set to indicate the elapsed time of a dive. A luminous dial with large numerals is also necessary. Additional features such as automatic winding, nonmagnetic components, and stop-watch action are available. Digital watches, with a stop-watch feature to indicate the elapsed time of a dive, are also approved for Navy use.

5-2.2.8 Depth Gauge. The depth gauge measures the pressure created by the water column above the diver and is calibrated to provide a direct reading of depth in feet of sea water. It must be designed to be read under conditions of limited visibility. The gauge mechanism is delicate and should be handled with care. Accurate depth determination is important to a diver's safety. The accuracy of a gauge must be checked in accordance with the planned maintenance system or whenever a malfunction is suspected. This can be done by taking the gauge to a known depth and checking the reading, or by placing it in a recompression chamber or test pressure chamber for depth comparison.

5-2.3 Optional Equipment. Depending upon the requirements of the specific diving operation, any or all of the following optional diving equipment may be necessary:

- Protective clothing
- Whistle
- Slate and pencil
- Tools and light
- Signal flares
- Tool bag
- Lines
- Wrist compass
- Witness float
- Snorkel
- Submersible cylinder pressure gauge
- Chem light
- Strobe light

5-2.3.1 Protective Clothing. A diver needs some form of protection from cold water, from heat loss during long exposure in water of moderate temperature, from chemical or bacterial pollution in the water, and from the hazards posed by marine life and underwater obstacles. Protection can be provided by a wet suit, or a dry suit with or without thermal underwear (Figure 5-8).

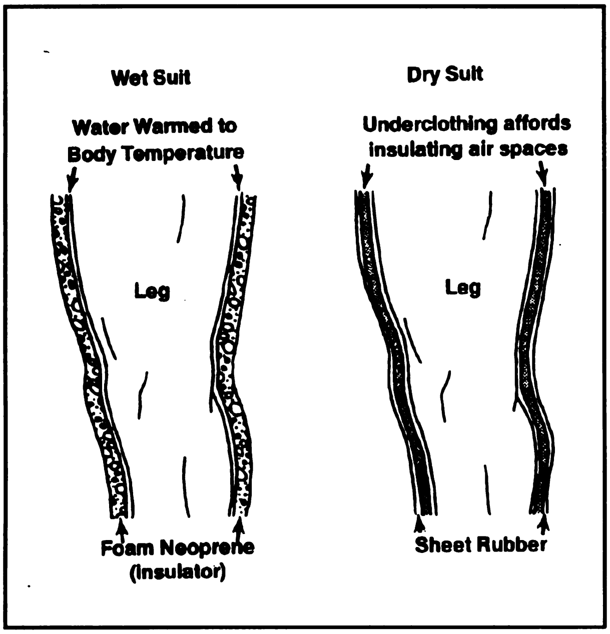


Figure 5-8. Comparison of Wet and Dry Suits.

The wet suit is a form-fitting suit, usually made of closed-cell neoprene. The suit traps a thin layer of water next to the diver's skin, where it is warmed by the diver's body. Wet suits are available in thicknesses of 1/8-, 3/16-, 1/4-, 3/8-, and 1/2-inch, with the thickest providing better insulation. The selection of the type of wet suit used is left to each diver. Standard size suits, as well as custom-fitted suits, are available at most commercial diving shops. Proper fit is critical in the selection of a wet suit. The suit must not restrict the diver's movements. A custom-fitted suit is recommended. The performance of a wet suit depends upon suit thickness, water temperature, and water depth.

The variable volume dry suit has proven to be effective in keeping divers warm in near-freezing water. It is typically constructed of 1/4-inch closed-cell neoprene with nylon backing on both sides. Boots are provided as an integral part of the suit, but the hood and three finger gloves are usually separate. The suit is entered by means of a water- and pressure-proof zipper. Inflation is controlled using inlet and outlet valves which are fitted into the suit. Air is supplied from a pressure reducer on an auxiliary cylinder or from the emergency gas supply or the SCUBA bottle. About 0.2 actual cubic foot of air is required for normal inflation. Because of this inflation, slightly more weight than would be used with a wet suit must be carried. Normally thermal underwear is worn under the suit for insulation.

Gloves are an essential item of protective clothing. They can be made of leather, cloth, or rubber, depending upon the degree and type of protection required. Gloves shield the hands from cuts and chafing, and provide protection from cold water. Some styles are designed to have insulating properties but may limit the diver's dexterity.

Wet or dry suits can be worn with hoods, gloves, boots, or hard-soled shoes depending upon conditions. If the diver will be working under conditions where the suit may be easily torn or punctured, the diver should be provided with additional protection such as coveralls or heavy canvas chafing gear.

5-2.3.2. Writing Slate. A rough-surfaced sheet of acrylic makes an excellent writing slate for recording data, for carrying or passing instructions, and for communicating between divers. A grease pencil or a graphite pencil should be attached to the slate with a lanyard.

5-2.3.3 Signal Flare. A signal flare is used to attract attention if the diver has surfaced away from the support crew. Any waterproof flare which can be carried and safely ignited by a diver can be used, but the preferred types are the Mk 13 Mod 0 and the Mk 99. These are day or night signals which give off a heavy reddish-orange smoke for daytime and a brillant red light at night. Each signal lasts for approximately 90 seconds. The night-end of the flare is identified by a ring of raised beads. Flares should be handled with care. For safety, each diver should carry a maximum of two flares.

5-2.3.4 Acoustic Beacons. Acoustic beacons or pingers are battery-operated devices that emit high-frequency signals when activated. The devices may be worn by divers to aid in keeping track of their position or attached to objects to serve as fixed points of reference. The signals can be picked up by hand-held sonar receivers, which are used in the passive or listening mode, at ranges of up to 1,000 yards. The hand-held sonar enables the search diver to determine the direction of the signal source and swim toward the pinger using the heading noted on a compass.

5-2.3.5 Lines and Floats. A lifeline should be used when it is necessary to exchange signals, keep track of the diver's location, or operate in limited visibility. There are three basic types of lifelines: the tending line, the float line, and the buddy line.

A single diver will be tended with either a tending line or a float line. When direct access to the surface is not available a tending line is mandatory. A float line may not be used.

The float line reaches from the diver to a suitable float on the surface. This float can be a brightly painted piece of wood, an empty sealed plastic bottle, a life ring, or any similar buoyant, visible object. An inner tube with a diving flag attached makes an excellent float and provides a handhold for a surfaced diver. If a pair of divers are involved in a search, the use of a common float gives them a rendezvous point. Additional lines for tools or other equipment can be tied to the float. A buddy line, 6 to 10 feet long, is used to connect the dive partners at night or when visibility is poor.

Any line used in SCUBA operations should be strong, and have neutral or slightly positive buoyancy. Nylon, dacron, and manila are all suitable materials. Always attach the lifeline to the diver, never to a piece of equipment that may be ripped away or may be removed in an emergency.

5-2.3.6 Snorkel. A snorkel is a simple breathing tube that allows a diver to swim on the surface for long or short distances face down in the water. This permits the diver to search shallow depths from the surface, conserving the SCUBA air supply. When snorkels are used for skin diving, they are often attached to the face mask with a lanyard or rubber connector on the opposite side of the regulator.

5-2.3.7 Compass. Small magnetic compasses are commonly used in underwater navigation. Such compasses are not highly accurate, but can be valuable when visibility is poor. Submersible wrist compasses, watches, and depth gauges covered by NAVSUPINST 5101.6 series are items controlled by the Nuclear Regulatory Commission and require leak testing and reporting every six months.

5-2.3.8 Submersible Cylinder Pressure Gauge. The submersible cylinder pressure gauge provides the diver with a continual readout of the air remaining in the cylinder(s). Various submersible pressure gauges suitable for Navy use are commercially available. Most are equipped with a two- to three-foot length of high-pressure rubber hose with standard fittings, and are secured directly into the first stage of the regulator. When turning on the cylinder air, the diver should turn the face of the gauge away in the event of a blowout. When worn, the gauge and hose should be tucked under a shoulder strap or otherwise secured to avoid its entanglement with bottom debris or other equipment. The gauge must be calibrated in accordance with the equipment planned maintenance system.

5-2.4 Other Equipment. Only diving equipment which has been certified or authorized for use by NAVSEAINST 10560.2 (series) shall be used in a Navy dive. However, many items, such as hand tools, which are not specifically listed in the ANU list, or do not fit under the scope of certification, and are deemed valuable to the success of the dive, can be used (refer to Paragraph 4-7.1). Items which shall not be used for any Navy dive follow.

- **Never use earplugs.** Earplugs keep water out of the external ear passages, making equalization of pressure impossible. The result could be an external ear squeeze, or damage to the eardrum if the plug is forced into the ear by the greater pressure at depth. Loss of hearing may result.

- **Never use goggles.** Goggles do not enclose the nose and, as a result, the pressure inside the goggles cannot be equalized. Serious tissue damage can result from the effects of squeeze caused by the lower pressure of the air space in the goggles, or from the water pressure forcing the rim of the goggles into the face or water into the goggles.

- **Decompression meters.** Any decompression meters approved for Navy use will be listed in NAVSEAINST 10560.2 (series). Divers must follow the decompression procedures described in Chapter 7 when conducting a dive requiring decompression without a decompression meter. Decompression SCUBA dives may be conducted only with the approval of the Commanding Officer when no other option exists.

5-3 AIR SUPPLY

An important early step in any SCUBA dive is computing the air supply requirement. The air supply requirement is a function of the expected duration of the dive at a specific working depth. The duration of the air supply in the SCUBA cylinders depends on the depth at which the air is delivered. Air consumption rate increases with depth.

The following paragraphs will present:

- A step-by-step demonstration of the recommended method for calculating duration of air supply

- Sources and standards for air used in SCUBA

- Methods for charging SCUBA cylinders

- Safety precautions for charging and handling cylinders.

5-3.1 Duration of Air Supply. The duration of the air supply of any given cylinder or combination of cylinders depends upon the diver's consumption rate, the depth of the dive, and the capacity and recommended minimum pressure of the cylinder(s). The effect of temperature is usually not significant in computing the duration of the air supply, unless the temperature conditions are extreme. In this event, the relationship discussed in Chapter 2, Charles' Law, must be applied.

A diver's consumption rate, as measured in standard cubic feet per minute (scfm), or respiratory minute volume, as measured in actual cubic feet per minute (acfm), varies directly with the diver's work rate. Figure 3-6 shows this basic relationship. The duration of the air supply of the various approved SCUBA cylinders (singles and doubles) may be calculated as shown below.

Equation 1:

$$C = \frac{D+33}{33} \times RMV$$

Where:

C = Diver's consumption rate, scfm

D = Depth, fsw

RMV = Diver's Respiratory Minute Volume, acfm (from Table 3-6)

The capacity of air which will be provided by a given cylinder must be expressed as the capacity of air which will actually be available to the diver, rather than as a total capacity of the cylinder. This available capacity may be determined as shown below.

Equation 2:

$$\frac{P_c - P_{rm}}{14.7} \times (FV \times N) = V_a$$

Where:

P_c = *Measured cylinder pressure, psig*

P_{rm} = *Recommended minimum pressure of cylinder, psig*

FV = Internal volume (scf)

N = Number of cylinders

V_a = *Capacity available (scf)*

To determine the duration, in minutes, of this available capacity, divide the capacity available (scf) by the consumption rate (scfm) as shown below.

Equation 3:

$$Duration = \frac{V_a}{C}$$

Where:

Va = Capacity available, scf

C = Consumption rate, scfm

Example: Determine the duration of the air supply of a diver doing moderate work at 70 fsw using twin 72-cubic-foot steel cylinders charged to 2,000 psig.

Solution: The diver's consumption rate at depth is determined from Figure 3-6 to be 1.2 acfm. Calculate this consumption rate in scfm (Equation 1):

$$C = \frac{D+33}{33} \times RMV$$

$$Consumption\ rate = \frac{70+33}{33} \times 1.2$$

$$Consumption\ rate = 3.75\ scfm$$

Table 5-1 gives the following data for 72-cubic-foot cylinders:

- Floodable Volume (from Table 5-2) = 0.420 (scf)
- Rated working pressure (psig) = 2250 psig
- Reserve pressure (psig) for twin 72-cubic-foot cylinders = 250 psig

Using these values in equation 2:

$$\frac{P_c - P_{rm}}{14.7} \times (FV \times N) = V_a$$

$$\frac{2000 - 250}{14.7} \times (.420 \times 2) = V_a = 100\,scf$$

The duration of the air supply is found using equation 3:

$$Duration = \frac{100\,scf}{3.75\,scfm} = 26.66\,minutes$$

In this example, the total time for the dive, from initial descent to surfacing at the end, is limited to 26 minutes.

5-3.2 Standards for Compressed Air. Compressed air must contain adequate oxygen and be free of excessive contamination from carbon monoxide, carbon dioxide, gaseous hydrocarbons, particulates (dirt and dust), oil mist, and other impurities. Contaminated breathing air can cause illness, unconsciousness, or death. Air used in SCUBA operations must meet the standards of purity established by the Commander, Bureau of Medicine regardless of the source of the air or the method used for charging the cylinders. These standards are:

- Oxygen concentration - 20-22% by volume
- Carbon dioxide - 1,000 ppm maximum
- Carbon monoxide - 20 ppm maximum
- Total hydrocarbons other than methane - 25 ppm maximum
- Particulates and oil mist - 5mg/m^3 maximum
- Odor and taste - not objectionable

These standards are applied to nonsaturation air dives and are measured at standard temperature and pressure. During normal gas analysis, hydrocarbons are first converted to methane and analyzed. The actual methane value is then subtracted from this result to give the value for unknown hydrocarbons. Unknown hydrocarbons should not exceed 25 ppm.

The Naval Sea Systems Command requires that an air sample be obtained semiannually from each air supply source in operable condition (Appendix I). To ensure the safety of Navy divers, NAVSEASYSCOM has established a unified program for sampling divers' breathing air. The Coastal Systems Station in Panama City, Florida has been designated as the central authority to schedule the sampling of the divers' air sources in use, and to ensure that the air samples are analyzed by a qualified laboratory.

5-3.3 Other Sources for Air. Compressed air meeting the established standards can usually be obtained from Navy sources. In the absence of appropriate Navy sources, air may be procured from commercial sources. Usually, any civilian agency or firm which handles compressed oxygen can provide pure compressed air. Air procured from commercial sources must meet the requirements of Grade A or C air as specified by FED SPEC BB-A-1034A and the diving air purity standards.

Air procured from any source must be contained in cylinders which meet required legal standards for high-pressure compressed air. Cylinders must bear a serial number, a DOT inspection stamp, a pressure rating, and the date of the last hydrostatic test.

5-3.4 Methods For Charging SCUBA Cylinders.

NOTE

> Paragraph 5-3.5 addresses safety precautions for charging and handling cylinders.

SCUBA cylinders shall be charged only with air that meets diving air purity standards. A diving unit can charge its own cylinders by one of two accepted methods: (1) by cascading or transferring air from banks of large cylinders into the SCUBA tanks; or (2) by using a high-pressure air compressor. Cascading is the fastest and most efficient method for charging SCUBA tanks. NAVSEAINST 10560.2 (series) lists approved high-pressure compressors and equipment authorized for SCUBA air sources.

The normal cascade system will include a minimum of three supply flasks manifolded together and feeding into a special SCUBA high-pressure whip. This whip consists of a SCUBA yoke fitting, a pressure gauge, and a bleed valve for relieving the pressure in the lines after charging a cylinder. A cascade system, with attached whip, is shown in Figure 5-9.

SCUBA charging lines shall be fabricated using SAE 100R7 hose for 3,000 psi service and SAE 100R8 hose for 5,000 psi service. These cited pressures are the working pressures for those hoses only when their bore diameters are 1/4-inch or less. Working pressure for the hose decreases as the bore diameter increases. For example, AE 100R7-6 has a bore diameter of 3/8-inch with working pressure of 2,250 psi. SAE 100R8-6 has a bore diameter of 3/8-inch with a working pressure of 4,000 psi and SAE 100R8-8 has a bore diameter of 1/2-inch with a working pressure of 3,500 psi. The service pressure of the SCUBA charging lines shall be no greater than the working pressure of the hose used.

The working pressure of a hose is determined as one-fourth of its burst pressure. While this criteria for working pressure was developed based

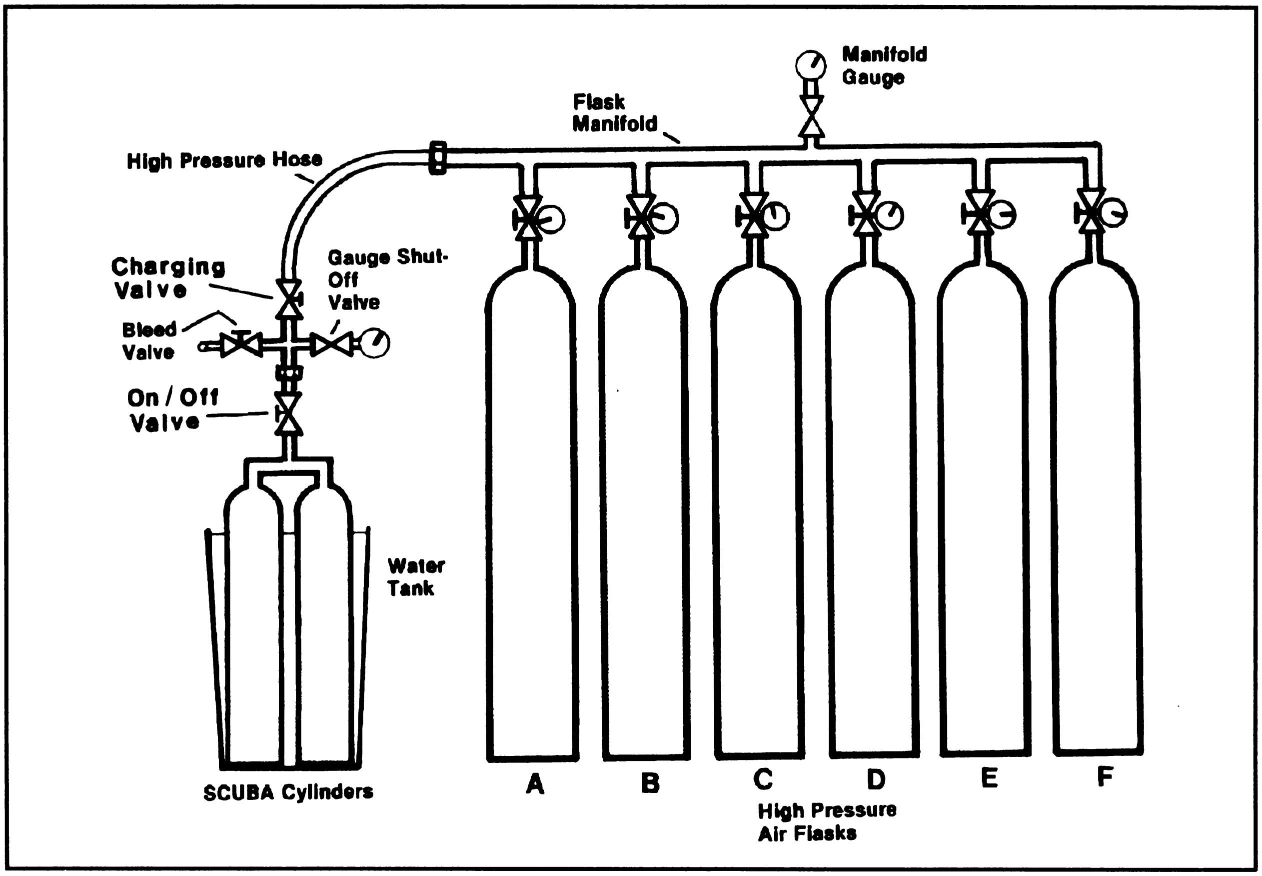


Figure 5-9. Cascading System for Charging SCUBA Cylinders.

on the characteristics of rubber hose, it has also been determined to be appropriate for use with the plastic hoses cited above.

Fleet units using charging lines shall not exceed the rated working pressure of the hose. If the charging line working pressure rating does not meet service requirements, restrict the service pressure of the hose to its working pressure and initiate replacement action immediately.

The use of strain reliefs made from cable, chain, 21-thread, or 3/8-inch nylon, married at a minimum of every eighteen inches and at the end of the hose is a required safety procedure to prevent whipping in the event of hose failure under pressure. Marrying cord will be 1/8-inch nylon or material of equivalent strength. Tie wraps, tape, and marlin are not authorized for this purpose.

Normally, SCUBA tanks are charged using the following operating procedures (OPs) which may be tailored to each unit:

(1) Check the existing pressure in the SCUBA cylinder with an accurate pressure gauge.

(2) After determining that the cylinder is within hydrostatic test date, attach it to the yoke fitting on the charging whip. For safety (in the event a cylinder explodes) and for efficiency (to dissipate heat generated in the charging process) it is advisable, when facilities are available, to immerse the SCUBA cylinder in a tank of water while it is being filled. A 55-gallon drum is a suitable container for this purpose.

(3) All fittings in the system shall be tightened.

(4) Close the bleed valve, place reserve mechanism lever in open (lever down) position and open cylinder (on/off) valve. This valve is fully opened with about two turns on the handle, counterclockwise. However, the valve must not be used in a fully open position as it may stick or be stripped if force is used to open a valve that is incorrectly believed to be closed. The proper procedure is to open the valve fully and then close or backoff one-quarter to one-half turn. This will not impede the flow of air.

(5) Close charging valve and open supply flask valve with the lowest psi reading (flask A). Slowly open the charging valve. The sound of the air flowing into the SCUBA cylinder is noticeable. Control the flow so that the pressure in the cylinder increases at a rate not to exceed 400 psig per minute. If unable to submerge SCUBA cylinders during charging, the charging rate must not exceed 200 psig per minute. The rate of filling must be controlled to prevent overheating; the cylinder must not be allowed to become too hot to touch.

(6) The pressure gauge shall be monitored carefully. When the reading approaches the rated pressure for the SCUBA cylinder, close the valve on the first cylinder and take a reading.

(7) Close the charging valve. Close the on/off valve on the SCUBA cylinder. Ensure that all valves in the system are firmly closed. Let the SCUBA cylinder cool to room temperature.

(8) When the cylinder is cool, the pressure will have dropped. Open the on/off valve on the SCUBA cylinder. Select a supply flask with higher pressure than the SCUBA rated limit. Open the supply valve on the flask (flask B). Throttle the charging valve to bring the SCUBA cyl-

inder up to the rated limit. Close all valves.

(9) Open the bleed valve and depressurize the lines. When air has stopped flowing through the bleed valve, disconnect the SCUBA cylinder from the yoke fitting. Reset the reserve mechanism (lever in up position).

(10) Place a piece of masking tape, or dust cover, over the O-ring seal face of the cylinder valve to help keep out dirt, prevent loss of O-ring, and provide an additional means for identifying a full SCUBA cylinder.

In the absence of high-pressure air systems, large volume air compressors can be used to charge SCUBA cylinders directly. However, few compressors are capable of delivering air in sufficient quantity at the needed pressure for efficient operation. Small compressors should be used only if no other suitable source is available.

If a suitable compressor is available, the basic charging procedure will be the same as that outlined for cascading except that the compressor will replace the bank of cylinders. Special considerations that apply to the use of air compressors are:

- If not part of a certified system, the compressor must be listed in NAVSEAINST 10560.2 (series), (ANU).
- The compressor must deliver air which meets the established purity standards.
- The compressor shall be equipped with ANU particulate filters, chemically active filters are not authorized.
- An engine-driven compressor must always be mounted so that there is no danger of taking in exhaust fumes from the engine, stack gas, or other contaminated air from local sources.
- Only approved diving compressor lubricants are to be used.

Additional information on the use of air compressors is found in Chapter 6.

5-3.5 Safety Precautions for Charging and Handling Cylinders. The safety rules applying to charging and handling of SCUBA cylinders are provided in Table 5-4.

5-4 SCUBA PROCEDURES

Operating procedures of SCUBA equipment, as with other diving modes, includes preparation of equipment, divers, actual conduct of the dive, and postdive operations.

5-4.1 Equipment Preparation. Prior to any dive, all equipment must be carefully inspected for signs of deterioration, damage, or corrosion and must be tested for proper operation. The procedures which follow are the result of many years of diving experience. Predive preparation procedures must be standardized, not altered for convenience, and must be the personal concern of each diver. All divers must always check their own equipment.

- Air cylinders - Inspect air cylinder exteriors and valves for rust, cracks, dents, and any evidence of weakness. Remove masking tape and/or valve cover and inspect O-ring. Verify that the reserve mechanism is closed (lever in up position) signifying a filled cylinder ready for use. Gauge the cylinders according to the following procedure:

(1) Attach pressure gauge to O-ring seal face of the on/off valve.

Table 5-4. Safety Precautions for Charging and Handling Cylinders.

1.	Carry cylinders by holding the valve and body of the cylinder. Avoid carrying a cylinder by the backpack or harness straps as the quick release buckle can be accidently tripped or the straps may fail.
2.	Do not attempt to fill any cylinder if the hydrostatic test date has expired or the cylinder appears to be substandard. Dents, severe rusting, bent valves, frozen reserve mechanisms, or evidence of internal contamination (e.g., water scales or rust) are all signs of unsuitability (Note 1).
3.	Always use gauges to measure cylinder pressure. Never position the dial of a gauge to which pressure is being applied near the operator's face.
4.	Never work on a cylinder valve while the cylinder is charged, except to attach a SCUBA regulator, pressure gauge, or to replace an O-ring.
5.	Make sure that the air reserve mechanism is **open** (lever down) before charging.
6.	Use only compressed air for filling conventional SCUBA cylinders **(never oxygen)**. The color code for air is black and the color code for oxygen is green.
7.	All fittings must be tight before pressurizing lines.
8.	Avoid excessive heat when charging. If possible, submerge the cylinder to be filled in a tank of water. If this cannot be accomplished, the charging rate should never exceed 200 psi per minute. Maximum charging rate for a submerged cylinder will not exceed 400 psi per minute.
9.	When fully charged, **close** the air reserve (lever up) and mark the tank filled by putting masking tape over the cylinder valve. This action prevents loss of O-ring.
10.	Handle charged cylinders with care; if damaged, or if the valve is accidently knocked loose, the cylinder tank can become an explosive projectile. A cylinder charged to 2,000 psi has enough potential energy to propel itself for some distance, tearing through any obstructions in its way.
11.	Store filled cylinders in a cool, shaded area. Never leave filled cylinders in direct sunlight.
12.	Cylinders should always be properly secured aboard ship or in a diving boat.
Note 1: See CGA Pamphlet C-6, Standards for Visual Inspection of Compressed Gas Cylinders.	

(2) Close gauge bleed valve and open air reserve mechanism (lever in down position). Slowly open the cylinder on/off valve, keeping a cloth over the face of the gauge.

(3) Read pressure gauge. The cylinder should not be used if the pressure is not sufficient to complete the planned dive.

(4) Close the cylinder on/off valve and open the gauge bleed valve. When the gauge reads zero remove the gauge from the cylinder. Close the air reserve mechanism (lever in up position). If the pressure in cylinders is 50 psi or greater over rating, open the cylinder on/off valve to bleed off excess and regauge the cylinder.

- Harness straps and backpack - Check for signs of rot and excessive wear. Adjust straps for individual use, and test quick-release mechanisms. Check backpack for cracks and other unsafe conditions.

- Breathing hoses - Check the hose(s) for cracks and punctures. Test the connections of each hose at the regulator and mouthpiece assembly by tugging on the hose. Check the clamps for corrosion and damage; replace as necessary.

- Regulator - Attach regulator to the cylinder manifold, ensuring that the O-ring is properly seated. Crack the cylindrer valve open and wait until the hoses and gauges have equalized. Next open the cylinder valve completely and then close (back off) one-quarter turn. Check for any leaks in the regulator by listening for the sound of escaping air. If a leak is suspected, determine the exact location by submerging the valve assembly and the regulator in a tank of water and watch for escaping bubbles. Frequently the problem can be traced to an improperly seated regulator and is corrected by closing the valve, bleeding the regulator, detaching, and reseating. If the leak is at the O-ring, and reseating does not solve the problem, replace the O-ring and check again for leaks.

- Life preserver/buoyancy compensator (BC) - Orally inflate preserver to check for leaks, and then squeeze out all air. The remaining gas should be removed after entry into the water by rolling onto the back and depressing the oral inflation tube just above the surface. Never suck the air out, as it may contain excessive carbon dioxide. Inspect the carbon dioxide cartridges to ensure they have not been used (seals intact) and are the proper size for the vest being used and for the depth of dive. The cartridges should be weighed in accordance with the Planned Maintenance System. The firing pin should not show wear and should move freely. The firing lanyards and life preserver straps must be free of any signs of deterioration. When the life preserver inspection is completed, place it where it will not be damaged. Life preservers should never be used as a buffer, cradle, or cushion for other gear.

- Face mask - Check the seal of the mask and the condition of the head strap. Check for cracks in the skirt and faceplate.

- Swim fins - Check straps and inspect blades for signs of cracking.

- Dive knife - Test the edge of the knife for sharpness, and ensure the knife is fastened securely in the scabbard. Verify that the knife can be removed from the scabbard without difficulty.

- Snorkel - Inspect the snorkel for obstructions, and check the condition of the mouthpiece.

- Weight belt - Check the condition of the weight belt and that the proper number of weights are secure and in place. Verify that the quick-release buckle is functioning properly.

- Submersible wrist watch - Ensure wrist watch is wound and set to the correct time. Inspect the pins and strap of the watch for wear.

- Depth gauge and compass - Inspect pins and straps. If possible, check compass with another compass. Make comparative checks on depth gauges to ensure depth gauges read zero fsw on the surface.

- Miscellaneous equipment - Inspect any other equipment which will be used on the dive as well as any spare equipment that may be needed during the dive including spare regulators, cylinders, and gauges. Check all protective clothing, lines, tools, flares, and other optional gear.

5-4.2 Diver Preparation. When the divers have completed inspecting and testing their equipment, they will report to the Diving Supervisor.

The divers will be given a predive briefing of the dive plan. This briefing is critical to the success and safety of any diving operation, and will be concerned with only the dive about to begin. All personnel directly involved in the dive should be included in the briefing. Minimum items to be covered are:

- Dive objectives
- Time and depth limits for the dive
- Task assignments
- Buddy assignments
- Work techniques and tools
- Phases of the dive
- Route to the work site
- Special signals
- Anticipated conditions
- Anticipated hazards
- Emergency procedures (i.e., aborted dive, injured diver, lost diver, etc.)

When the Diving Supervisor determines all requirements for the dive have been met, the divers may dress for the dive.

5-4.2.1 Donning Gear. Although SCUBA divers should be able to put on all gear themselves, the assistance of a tender is encouraged. Dressing sequence is important as the weight belt must be outside of all backpack harness straps and other equipment in order to facilitate its quick release in the event of an emergency. The following is the dressing sequence to be observed:

(1) Protective clothing. Ensure adequate protection is provided with a wet suit.

(2) Boots and hood.

(3) Dive knife.

(4) Life preserver, with inflation tubes in front and the actuating lanyards exposed and accessible.

(5) SCUBA. Most easily donned with the aid of a tender to hold the cylinders in position while the diver fastens and adjusts the harness. The SCUBA should be worn centered on the diver's back as high up as possible but not high enough to interfere with head movement. All quick-release buckles must be positioned so that they can be reached by either hand. All straps must be pulled snug so the cylinders are held firmly against the body. The ends of the straps must hang free so the quick-release feature of the buckles will function. If the straps are too long, they should be cut and the ends whipped with small line or a plastic sealer. At this time, the cylinder on/off valve should be opened fully and then backed one-quarter to one-half turn. Ensure buoyancy compensator whip is connected to the buoyancy compensator.

(6) Accessory equipment (diving wrist watch, depth gauge, snorkel). Tuck snorkel in belt or under a strap.

(7) Weight belt.

(8) Gloves.

(9) Swim fins.

(10) Face mask.

5-4.2.2 Predive Inspection. The divers must report to the Diving Supervisor for a final inspection. During this final predive inspection the Diving Supervisor must:

(1) Ensure that the divers are physically and mentally ready to enter the water.

(2) Verify that all divers have all minimum required equipment (SCUBA, face mask, life preserver or bouyancy compensator, weight belt, dive knife, scabbard, swim fins, watch and depth gauge).

(3) When diving with nonmagnetic SCUBA in an operational EOD dive where a low magnetic signature is required and a buddy line is used, only one depth gauge and one watch per dive team is required.

(4) Verify that the cylinders have been gauged and that the available volume of air is sufficient for the planned duration of the dive.

(5) Ensure that all quick-release buckles and fastenings can be reached by either hand and are properly rigged for quick release.

(6) Verify that the weight belt is outside of all other belts, straps, and equipment, and will not become pinched under the bottom edge of the cylinders.

(7) Verify that the life preserver or bouyancy compensator is not constrained, is free to expand, and that all air has been evacuated.

(8) Check position of the knife to ensure that it will remain with the diver no matter what equipment is left behind.

(9) Ensure the cylinder valve is open fully and backed off one-quarter to one-half turn.

(10) Ensure the hose supplying air passes over the diver's right shoulder and the exhaust hose on the double-hose unit passes over the left shoulder. Double-hose regulators are attached so that the exhaust ports face up when the tank is standing upright.

(11) With mouthpiece or full face mask in place, breathe in and out for several breaths, ensuring that the demand regulator and check valves are working correctly.

(12) With a single-hose regulator, depress and release the purge button at the mouthpiece and listen for any sound of leaking air. Breathe in and out several times ensuring valves are working correctly.

(13) Give the breathing hose(s) and mouthpiece a final check; ensure that none of the connections have been pulled open during the process of dressing.

(14) Check that air reserve mechanism lever is up (closed position).

(15) Conduct a brief final review of the dive plan.

(16) Verify that dive signals are displayed and personnel and equipment are ready to signal other vessels in the event of an emergency.

The divers are now ready to enter the water, where their SCUBA will be given another brief inspection by their dive partners or tenders prior to descent.

5-4.2.3 Water Entry. There are several methods of water entry, with the choice usually determined by the nature of the diving platform.

Whenever possible, entry should be made by ladder, especially in unfamiliar waters.

Several basic rules apply to all methods of entry:

- Look before jumping or pushing off from the platform or ladder.
- Tuck chin into chest and hold the cylinders with one hand to prevent manifold from hitting the back of the head.
- Hold the mask in place with the fingers and the mouthpiece in place with the heel of the hand.

The front jump, or step-in, is the most frequently used method and is best used from a stable platform or vessel (Figure 5-10). The divers should not actually jump into the water but simply take a large step out from the platform, keeping legs in an open stride. They should try to enter the water with a slightly forward tilt of the upper body so that the force of entry will not cause the cylinder to hit the back of the head.

The rear roll is the preferred method for entering the water from a small boat (Figures 5-11 and 5-12). A fully outfitted diver, standing on the edge of a boat, would upset the stability of the craft and would be in danger of falling either into the boat or into the water. To execute a rear roll, the diver sits on the gunwale of the boat, facing inboard. With chin tucked in and one hand holding the mask and mouthpiece in place (just as in all other methods of entry), the diver rolls backward, basically moving through a full backward somersault.

Figures 5-13 through 5-15 demonstrate the rear step-in, side roll, and front roll methods of entry.

If working from the beach, the divers choose their method of entry according to the condition of the surf and the slope of the bottom. If the water is calm and the slope gradual, the divers can walk out, carrying their swim fins until they reach water deep enough for swimming. If in a moderate to high surf, the divers, wearing swim fins, should walk backwards into the waves until they have enough depth for swimming. They

Figure 5-10. SCUBA Entry Technique - Front Jump or Step-In. On edge of platform, one hand holding face mask and regulator, the other holding his cylinders, the diver takes a long step forward keeping his legs astride.

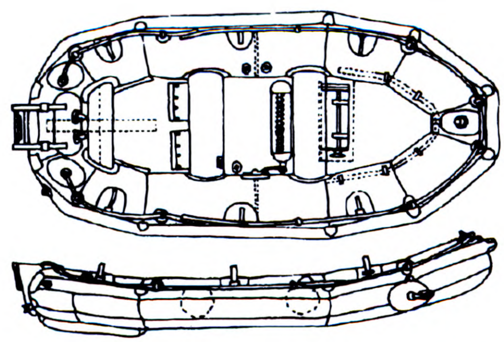


Figure 5-11. SCUBA Diving Boat. The seven-man inflatable boat is normally employed in Navy SPECWAR Operations. Its design includes all the required features of a SCUBA boat: mobility, ease of entry to and from the water, stability, and adequate space.

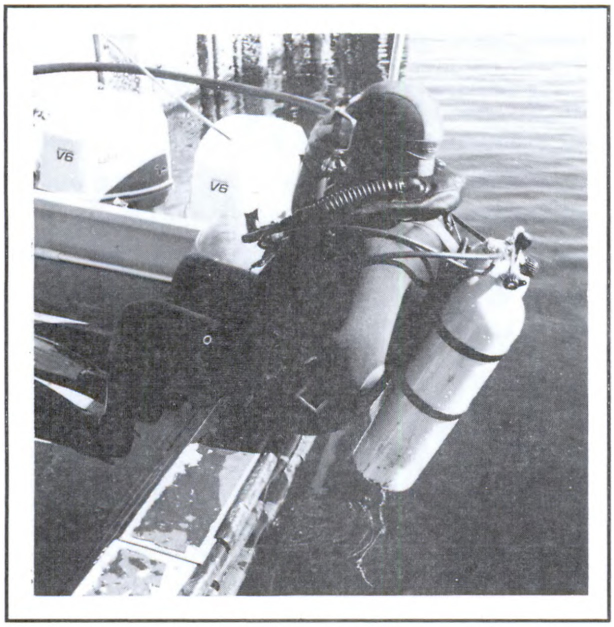


Figure 5-12. SCUBA Entry Technique - Rear Roll. The diver, facing inboard, sits on the gunwale. With chin tucked in, holding his mask, mouthpiece, and cylinders, the diver rolls backwards basically completeing a full backward somersault.

Figure 5-13. Scuba Entry Technique-Rear Step-In. The diver steps backward pushing himself away with his feet.

Figure 5-14a. SCUBA Entry Technique - Side roll. 1. Tender assists diver in taking a seated position. Tender stands clear as diver holds his mask and cylinders...

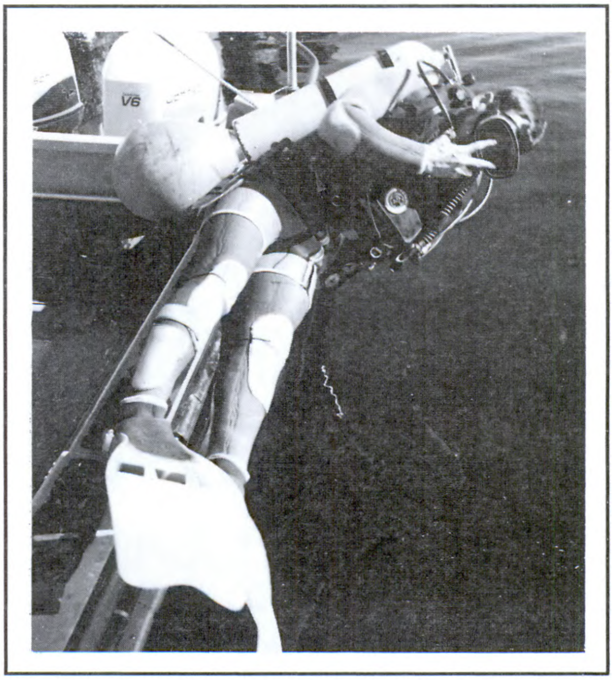


Figure 5-14b. SCUBA Entry Technique - Side Roll. 2. ...and rolls into water.

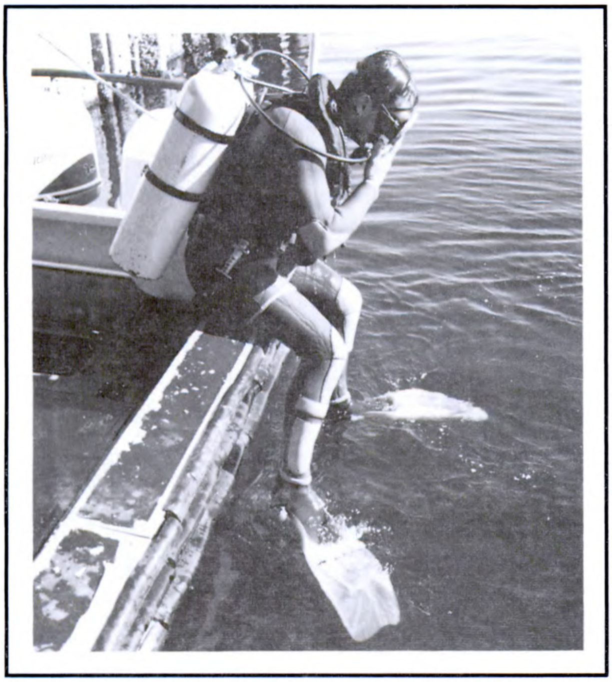


Figure 5-15a. SCUBA Entry Technique - Front Roll.
1. Diver sits on edge of platform with a slight forward lean to offset the weight of his cylinders.

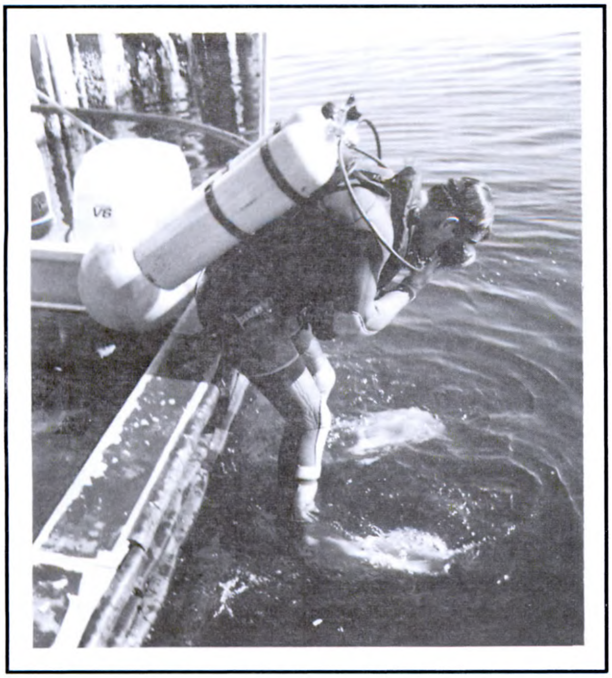


Figure 5-15b. SCUBA Entry Technique - Front Roll.
2. Holding his mask and cylinders, the diver leans forward.

should gradually settle into the waves as the waves break around them.

5-4.2.4 Predescent Surface Check. In the water, and prior to descending to operating depth, the divers make a final check of their equipment. They must:

- Make a breathing check of the SCUBA. Breathing should be easy, without resistance, and with no evidence of water leaks.
- Visually check dive partner's equipment for leaks, especially at all connection points (i.e., cylinder valve, hoses at regulator and mouthpiece).
- Check partner for loose or entangled straps.
- Check face mask seal. A small amount of water may enter the mask upon the diver's entry into the water. The mask may be cleared through normal methods (Paragraph 5-4.3.2).
- Check buoyancy. SCUBA divers should strive for neutral buoyancy. When carrying extra equipment or heavy tools, the divers might easily be negatively buoyant unless the weights are adjusted accordingly.
- If wearing a dry suit, check for leaks. Adjust suit inflation as necessary for proper buoyancy.
- Orient position with the compass or other fixed reference points.

When satisfied that all equipment checks out properly, the divers report their readiness to the Diving Supervisor. The Diving Supervisor directs the divers to zero their watches and bottom time begins. The Diving Supervisor gives a signal to descend and the divers descend below the surface.

5-4.3 Surface Swimming. The diving boat should be moored as near to the dive site as possible. While swimming, dive partners must keep visual contact with each other and other divers in the group. They should be oriented to their surroundings to avoid swimming off course. The most important factor in surface swimming with SCUBA is to maintain a relaxed pace to conserve energy. The divers should keep their masks on and breathe through the snorkel.

Divers should use only their legs for propulsion and employ an easy kick from the hips without lifting the swim fins from the water. Divers can rest on their backs and still make headway by kicking. Swimming assistance can be gained with a partial inflation of the life preserver or buoyancy compensator. However, the preserver must be deflated again before the dive begins.

When surface swimming with a single- or double-hose SCUBA, care should be exercised to avoid holding the mouthpiece in such a position that air will free-flow from the system.

5-4.4 Descent. The divers may swim down or they may use a descending line and pull themselves down. The rate of descent will generally be governed by the ease with which the divers will be able to equalize the pressure in their ears and sinuses, but it shall never exceed 120 feet per minute. If either diver experiences difficulty in clearing, both divers must stop and ascend until the situation is resolved. If the problem persists after several attempts to equalize, the dive shall be aborted and both divers shall return to the surface. When visibility is poor, the divers should keep an arm extended to ward off any obstructions.

Upon reaching the operating depth, the divers must orient themselves to their surroundings, verify the site, and make a check of the underwater conditions. If these appear to be radically different from those anticipated and seem to pose a hazard, the dive should be aborted and the conditions reported to the Diving Supervisor. The dive should be aborted if the observed conditions call for any major change in the dive plan. The divers should surface, discuss the situation with the Diving Supervisor, and modify the dive plan.

5-4.5 SCUBA Underwater Procedures. In a SCUBA dive, bottom time is at a premium because of a limited supply of air. Divers must pace their work, conserve their energy, and take up each task or problem individually. At the same time they must be flexible. They must be ready to abort the dive at any time they feel that they can no longer progress toward the completion of their mission or when conditions are judged unsafe. The divers must be alert for trouble at all times, and divers must monitor the condition of the dive partner constantly.

5-4.5.1 Breathing Technique. When using SCUBA for the first time, a novice diver is likely to experience anxiety and breathe more rapidly and deeply than normal. The diver must learn to breathe in an easy, slow rhythm at a steady pace. The rate of work should be paced to the breathing cycle, rather than changing the breathing to support the work rate. If a diver is breathing too hard, the diver should pause in the work until breathing returns to normal. If normal breathing is not restored soon, the diver must signal the dive partner, break off the operation, and together they should ascend to the surface.

Some divers, knowing that they have a finite air supply, will attempt to conserve air by holding their breath. One common technique is to skip-breathe: to insert an unnatural, long pause between each breath.

WARNING

Breathholding and skip-breathing frequently lead to hypercapnia and are not to be used at any time.

Increased breathing resistance results from the design of the equipment and increased air density. For normal diving, a marked increase of breathing resistance should not occur until the primary air supply has been almost depleted. This increase in breathing resistance is a signal to the diver to activate the reserve air supply and to begin an ascent with the partner immediately. When equipped with a submersiable bottle gauge, the diver shall monitor his air supply pressure and must terminate the dive whenever bottle pressure is reduced to 500 psi.

5-4.5.2 Mask Clearing. Some water seepage into the face mask is a normal condition and is often useful in defogging the lens. From time to time the quantity may build to a point that it must be removed. On occasion, a mask may become dislodged and flooded. To clear a flooded mask not equipped with a purge valve, the diver should roll to the side or look upward, so that the water will collect at the side or bottom of the mask (Figure 5-16). Using either hand, the diver applies a firm direct pressure on the opposite side or top of the mask, and exhales firmly and steadily through the nose. The water will be forced out under the skirt of the mask. For a mask with a purge valve, the diver tilts the head so that the accumulated water covers the valve, presses the mask against the face, and then exhales firmly and steadily through the nose. The increased pressure in the mask will force the water through the valve. Occasionally, more than one exhalation will be required.

5-4.5.3 Hose and Mouthpiece Clearing. The mouthpiece and the breathing hoses can become flooded if the mouthpiece is accidentally pulled from the mouth. With a single-hose SCUBA this is not a serious problem since the hose (carrying air at medium pressure) will not flood and the mouthpiece can be cleared quickly by depressing the purge button as the mouthpiece is being replaced.

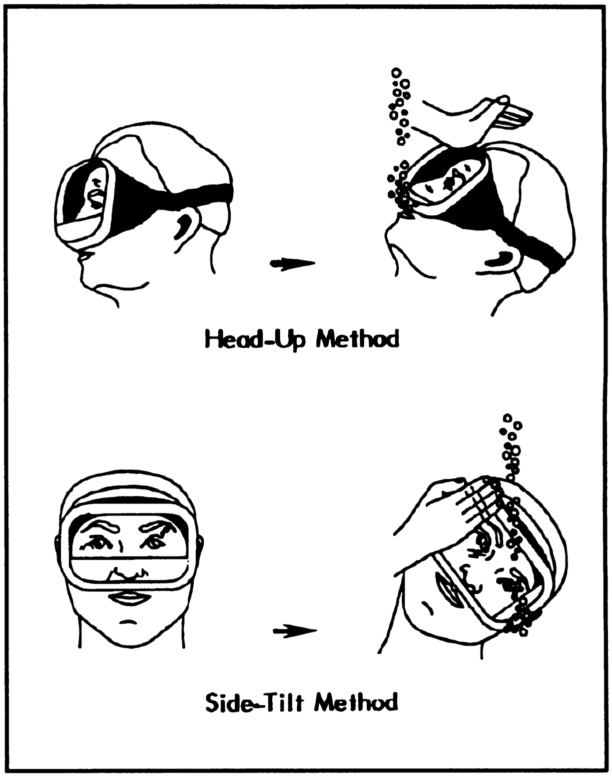


Figure 5-16. Clearing a Face Mask. To clear a flooded facemask, push gently on the upper or side portion of the mask and exhale through the nose into the mask. As water is forced out, tilt the head backward or sideway until the mask is clear.

To clear a double-hose SCUBA regulator which has flooded, the diver, swimming in a horizontal position, should grasp the mouthpiece. The diver should then blow into the mouthpiece, forcing any water trapped in the mouthpiece out through the regulator's exhaust ports. The diver should carefully take a shallow breath. There may still be water trapped in the mouthpiece and, if so, the diver should blow through it once more and resume normal breathing. If the diver is out of breath, he should roll over onto his back and the regulator will free flow.

5-4.5.4 Swimming Technique. In underwater swimming, all propulsion comes from the action of the legs. The hands are used for maneuvering. The leg kick should be through a large, easy arc with main thrust coming from the hips. The knees and ankles should be relaxed. The rhythm of the kick should be maintained at a level that will not tire the legs unduly or bring on muscle cramps.

5-4.5.5 Diver Communications. Some common methods of diver communications are: through-water communication systems, hand signals, slate boards, and line-pull signals. Communication between the surface and a diver can be best accomplished with through-water voice communications. However, when through-water communications are not available, hand signals or line-pull signals can be used.

Presently, several types of through-water communication systems are available for SCUBA diving operations. Acoustic systems provide one-way, topside-to-diver communications. The multidirectional audio signal is emitted through the water by a submerged transducer. Divers can hear the audio signal without the aid of signal receiving equipment. Amplitude Modulated (AM) and Single Sideband (SSB) systems provide round robin, diver-to-diver, diver-to-topside, and topside-to-diver communications. Both the AM and SSB systems require transmitting and receiving equipment to be worn by the divers. AM systems provide a stronger signal and better intelligibility but are restricted to line-of-sight use. SSB systems provide superior performance in and around obstacles. Before any through-water communication system is used, NAVSEAINST 10560.2 (series) (ANU List) should be consulted.

Navy divers shall only use hand signals which have been approved for Navy diving use. Figure 5-17 presents the U.S. Navy approved hand signals. Under certain conditions, special signals applicable to a specific mission may be devised and approved by the Diving Supervisor. If visibility is poor, the dive partners may be forced to communicate with line-pull signals on a buddy line. Line-pull signals are discussed in Chapter 6. Hand signals and line-pull signals should be delivered in a forceful, exaggerated manner so that there is no ambiguity and no doubt that a signal is being given. Every signal must be acknowledged.

5-4.5.6 Buddy System. The greatest single safety practice in Navy SCUBA operations is the use of the buddy system. Dive partners operating in pairs are responsible for both the assigned task and each other's safety. The basic rules for buddy diving are:

- Always maintain contact with the dive partner. In good visibility, keep the parter in sight. In poor visibility, use a buddy line.
- Know the meaning of all hand and line-pull signals.
- If a signal is given, it must be acknowledged immediately. Failure of a dive partner to respond to a signal must be considered an emergency.
- Monitor the actions and apparent condition of the dive partner. Know the symptoms of diving ailments. If at any time the dive partner appears to be in distress or is acting in an abnormal manner, determine the cause immediately and take appropriate action.
- Never leave a partner unless the partner has become trapped or entangled and cannot be freed without additional assistance. If surface assistance must be sought, mark the location of the distressed diver with a line and float or other locating device. Do not leave a partner if voice communications or line-pull signals are being used; contact the surface and await assistance or instructions.

SCUBA Hand Signals

Signal		Meaning	Comment
1.	Clenched fist.	STOP	
2.	Hand flat, fingers together, palm out thumb down then hand rocking back and forth on axis of forearm.	SOMETHING IS WRONG	This is the opposite of Okay. The signal does not indicate an emergency.
3a/b.	Thumb and forefinger making a circle with three remaining fingers extended (if possible).	I AM OKAY. ARE YOU OKAY?	Divers wearing mittens may not be able to extend three remaining fingers distinctly (see 3a/b drawings of signal). Short range use.
4a.	Right hand raised overhead giving Okay signal with fingers.	OKAY ON THE SURFACE (CLOSE)	Given when diver is close to pickup boat.
4b.	Both hands touching overhead with both arms bent at 45° angle.	OKAY ON THE SURFACE (DISTANT)	Given when diver is at a distance from the pickup boat.
5.	Hand waving overhead (diver may also thrash hand in water).	DISTRESS, HELP. PICK ME UP.	Indicates immediate aid is required.
6.	Diver points to either watch or depth gauge.	WHAT TIME? or WHAT DEPTH?	When indicating time, this signal is commonly used for bottom time remaining.
7.	Two fingers up, two fingers and thumb against palm.	GO DOWN, GOING DOWN.	
8.	Four fingers pointing up, thumb against palm.	GO UP, GOING UP.	
9a.	Hand slashing or chopping at throat.	I'M OUT OF AIR.	Indicates the signaler cannot breathe.
9b.	Fingers pointing to mouth or regulator.	I NEED TO BUDDY BREATHE.	Signaler's regulator may be in or out of mouth.
10.	Hand to chest, repeated.	COME HERE.	
11.	Finger to chest, repeated.	ME or WATCH ME.	
12.	Fingers together and arm moving in an over, under, or around movement.	OVER, UNDER, or AROUND	Diver signals intention to move over, under, or around an object.
13.	Fingers and thumb spread out and hand moving back and forth in a level position.	LEVEL OFF or HOW DEEP?	
14.	Fist clenched with thumb pointing up, down, right, or left.	GO THAT WAY.	Indicates which direction to swim.
15.	Fingers clenched, thumb and hand rotating right and left.	WHICH DIRECTION?	
16.	Diver pointing to either ear.	EAR TROUBLE	Divers should ascend a few feet. If problem continues, both divers must surface.
17.	Both arms crossed over chest.	I AM COLD.	
18.	Hand extended, palm down, in short up and down motion.	TAKE IT EASY or SLOW DOWN.	
19.	Index fingers extended, one hand forward of the other.	YOU LEAD, I'LL FOLLOW.	

Figure 5-17. SCUBA Hand Signals (sheet 1 of 4).

Figure 5-17. SCUBA Hand Signals (sheet 2 of 4).

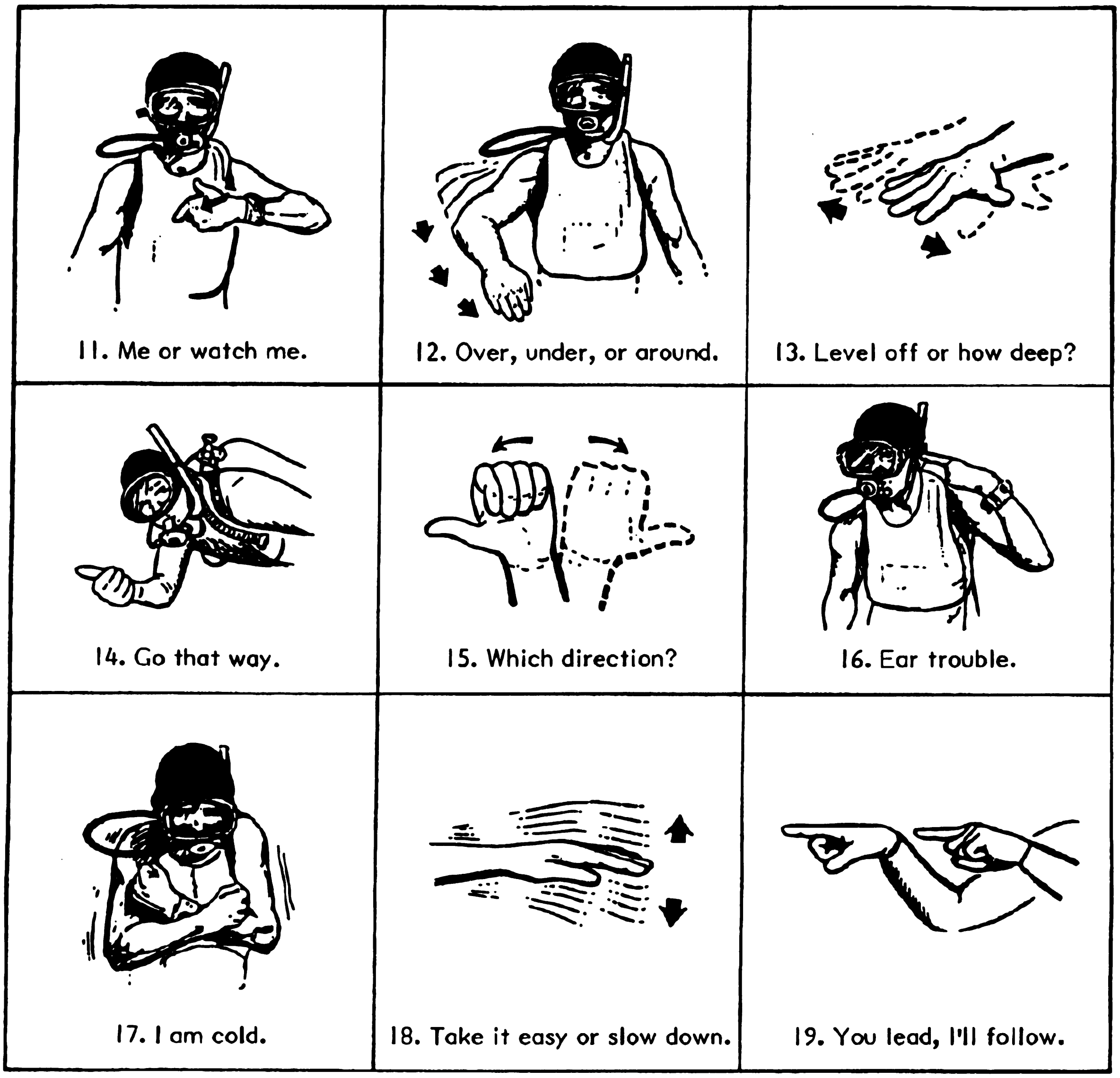


Figure 5-17. SCUBA Hand Signals (sheet 3 of 4).

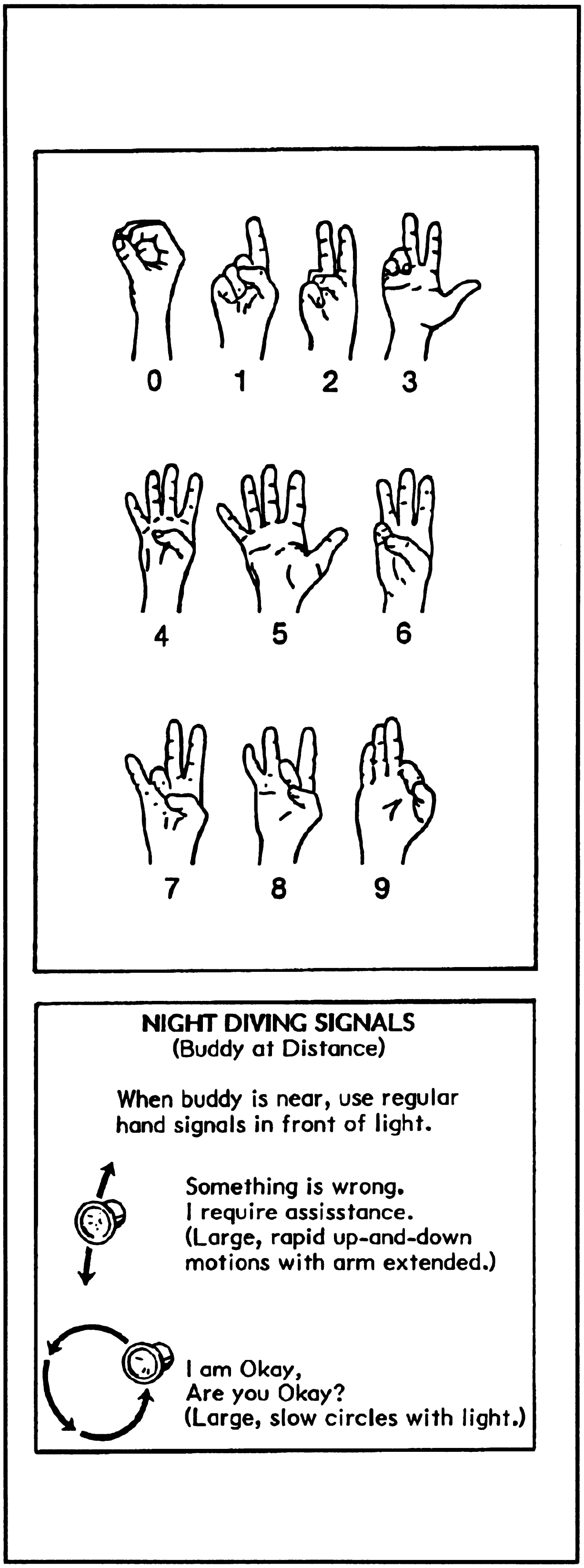


Figure 5-17. SCUBA Hand Signals (sheet 4 of 4).

- Establish a lost-diver plan for any dive. If partner contact is broken, follow the plan.
- If one member of a dive team aborts a dive, for whatever reason, the other member also aborts and both must surface.
- Know the proper method of buddy breathing.

5-4.5.7 Buddy Breathing. If a diver runs out of air or the SCUBA malfunctions, air may be shared with the dive partner. The most efficient method of buddy breathing is for the two divers to face each other, each alternately breathing from the same mouthpiece while ascending. Buddy breathing may be used only in an emergency and must be practiced so that each diver will be thoroughly familiar with the procedure:

(1) The distressed diver should remain calm, and the partner signaled by pointing to SCUBA mouthpiece.

(2) The partner and the distressed diver should hold on to each other by grasping a strap or the free arm. The divers must be careful not to drift away from each other.

(3) The partner must make the first move by taking a breath and passing mouthpiece to the distressed diver. The distressed diver must not grab for the dive partner's mouthpiece. The dive partner guides it to the distressed diver's mouth. Both divers maintain direct hand contact on the mouthpiece.

(4) The mouthpiece may have flooded during the transfer. In this case, it must be cleared either by use of the purge button (if single-hose) or by exhaling into the mouthpiece before a breath can be taken. If using a double-hose regulator, the mouthpiece should be kept slightly

higher than the regulator so that free-flowing air will help keep the mouthpiece clear.

(5) The distressed diver should take two full breaths (exercising caution in the event that all of the water has not been purged) and guide the mouthpiece back to the partner. The partner should then purge the mouthpiece as necessary and take two breaths.

(6) The divers should repeat the breathing cycle and establish a smooth rhythm. No attempt should be made to surface until the cycle is stabilized and the proper signals have been exchanged.

WARNING

During ascent, the diver without the mouthpiece must exhale to offset the effect of decreasing pressure on the lungs which could cause an air embolism.

(7) Buddy breathing may also be accomplished by use of an "octopus" (secondary second stage regulator). Approved secondary second stage regulators are contained in the diving equipment authorized for Navy use (NAVSEAINST 10560.2 series).

5-4.5.8 Tending. When a diver is being tended by either a line from the surface or a buddy line, several basic considerations apply:

- Lines should be kept free of slack.
- Line signals must be given in accordance with the procedures given in Chapter 6.
- Any signals via the line must be acknowledged immediately by returning the same signal.
- The tender should signal the diver with a single pull every two or three minutes to determine if the diver is all right. A return signal of one pull indicates that the diver is all right.
- If the diver fails to respond to line-pull signals after several attempts, the standby diver must investigate immediately.
- The diver must be particularly aware of the possibilities for the line becoming snagged or entangled.

If a surface line is not being used, the tender must keep track of the general location of the divers by observing the bubble tracks or the float or locating device.

5-4.5.9 Working With Tools. The near-neutral buoyancy of a SCUBA diver poses certain problems when working with tools. A diver is at a disadvantage when applying leverage with tools. When force is applied to a wrench, for example, the diver is pushed away from the wrench and very little torque is applied to the wrench. If both sides of the work are accessible, two wrenches - one on the nut and one on the bolt - should be used. By pulling on one wrench and pushing on the other, the counter force permits most of the effort to be transmitted to the work. When using any tool which requires leverage or force (including pneumatic power tools), the diver should be braced with feet, a free hand, or a shoulder. When using externally-powered tools with SCUBA, the diver must have voice communications with the Diving Supervisor.

Any tools to be used should be organized in advance. The diver should carry as few items as possible. If many tools are required, a canvas tool bag should be used to lower them to the diver as needed. Further guidelines for working underwater are provided in the *U.S. Navy Underwater Ship Husbandry Manual* (NAVSEA S0600-AA-PRO-010). Authorized power tools are listed in NAVSEAINST 10560.2 (series).

5-4.5.10 Adapting To Underwater Conditions. Through careful and thorough planning, the divers can be properly prepared for the underwater conditions at the diving site and be provided with appropriate auxiliary equipment, protective clothing, and tools. However, the diver may have to employ the following techniques when appropriate to offset the effects of certain underwater conditions.

- Stay two or three feet above a muddy bottom; use a restricted kick and avoid stirring up the mud. A diver should be positioned so that the current will carry away any clouds of mud.

- Avoid coral or rocky bottoms, which may cause cuts and abrasions.

- Avoid abrupt changes of depth.

- Do not make excursions away from the dive site unless such excursions have been included in the dive plan.

- Be aware of the peculiar properties of light underwater. Depth perception is altered so that an object that appears to be three feet away is actually four feet away, and objects appear larger than they actually are.

- Be aware of unusually strong currents, particularly rip currents near a shoreline. If caught in a rip current, relax and ride along with it until it diminishes enough to swim clear.

- If practical, swim against a current to approach a job site; the return swim with the current will be easier and will offset some of the fatigue caused by the job.

- Stay clear of lines or wires which are under stress.

5-4.6 Normal Ascent. When it is time to return to the surface, either diver may signal the end of the dive. When the signal has been acknowledged, the divers will ascend to the surface together at a rate not to exceed 30 feet per minute. For a normal ascent, the divers will breathe steadily and naturally. Divers must never hold their breath during ascent, because of the danger of an air embolism.

While ascending, divers must keep an arm extended overhead to watch for obstructions and should spiral slowly while rising to obtain a full 360 degree scan of the water column.

5-4.7 Emergency Free Ascent. If a diver is suddenly without air or if the SCUBA is entangled and the dive partner cannot be reached quickly, a free ascent must be made.

5-4.7.1 Free Ascent Procedures. Guidelines for a free ascent follow.

(1) Drop any tools or objects being carried by hand.

(2) Abandon the weight belt.

(3) If the SCUBA has become entangled and must be abandoned, actuate the quick-release buckles on the waist, chest, shoulder, and crotch straps. Slip an arm out of one shoulder strap and roll the SCUBA off the other arm. An alternate method is to flip the SCUBA over the head and pull out from underneath. Ensure that the hoses do not wrap around or otherwise constrict the neck. The neck straps which are packed with some single-hose units can complicate the overhead procedure

and should be disconnected from the unit and not used.

(4) If the reason for the emergency ascent is a loss of air, drop all tools and the weight belt and actuate the life preserver to surface immediately. Do not drop the SCUBA unless it is absolutely necessary. During the ascent, the pressure differential between the air in the cylinders and the air in the medium pressure chamber of the regulator will increase. This permits some of the air remaining in the cylinders to be supplied to the diver.

(5) If a diver is incapacitated or unconscious and the dive partner anticipates difficulty in trying to swim the injured diver to the surface, the partner should activate the life preserver or inflate the buoyancy compensator. The weight belt may have to be released also. However, the partner should not lose direct contact with the diver.

(6) During ascent, exhale continuously. Let the expanding air in the lungs escape freely.

5-4.7.2 Ascent From Under A Vessel. When underwater ship husbandry tasks are required. Surface-supplied lightweight equipment is preferred. SCUBA diving is permitted under floating hulls; however, a tending line to the SCUBA diver must be provided. In the event of casualty and the lack of immediate assistance by the dive partner, the SCUBA diver will be able to return to the surface using the tending line. Ships are often moored against closed-face piers or heavy camels, and care must be exercised to ensure that the tending line permits a clear path for emergency surfacing of the diver. Due to the unique nature of Special Warfare diving, the use of tending lines is not practical and is not required for Special Warfare diving.

SCUBA dive plans on deep-draft ships should restrict diving operations to one quadrant of the hull at a time. This theoretical quartering of the ship's hull will minimize potential diver disorientation caused by multiple keel crossings or fore and aft confusion.

When notified of a lost diver, a jackstay search will be conducted by a tended diver in the area where the lost diver was last seen.

Predive briefs must include careful instruction on life preserver use when working under a hull to prevent panic blowup against the hull. Life preservers should not be fully inflated until after the diver passes the turn of the bilge.

5-4.8 Decompression. Open-circuit SCUBA dives are normally planned as no-decompression dives. Open-circuit SCUBA dives requiring decompression may be made only when considered absolutely necessary and authorized by the Commanding Officer or Officer in Charge (OIC). Under this unique situation, the following provides guidance for SCUBA decompression diving.

The Diving Supervisor will determine the required bottom time for each dive. Based upon the time and depth of the dive, the required decompression profile from the tables presented in Chapter 7 will be computed. The breathing supply required to support the total time in the water must then be calculated. If the air supply is not sufficient, a backup SCUBA will have to be made available to the divers. The backup unit can be strapped to a stage or tied off on a descent line which also has been marked to indicate the various decompression stops to be used.

When the divers have completed the assigned task, or have reached the maximum allowable bottom time prescribed in the dive plan, they must ascend to the stage or the marked line, and signal the surface to begin decompression. With the stage being handled from the surface, the divers will be taken through the appropriate stops while the timekeeper controls the progress. Before each move of the stage, the tender will signal the divers to prepare for the lift and the divers will signal back when prepared. When using a marked line, the tender will signal when each stop has been completed, at which point the divers will swim up, signalling their arrival at the next stop. Stop times will always be regulated by the tender.

In determining the levels for the decompression stops, the sea state on the surface must be taken into consideration. If large swells are running, the stage or marker line will be constantly rising and falling with the movements of the surface-support craft. The depth of each decompression stop should be calculated so that the divers' chests will never be brought above the depths prescribed for the stops in the decompression tables.

In the event of an accidental surfacing or an emergency, the Diving Supervisor will have to determine if decompression should be resumed in the water or if the services of a recompression chamber are required. The possibility of having to make such a choice should be anticipated during the planning stages of the operation (Chapters 4 and 8).

5-4.9 Surfacing and Leaving the Water. When approaching the surface, divers must not come up under the support craft or any other obstruction. They should listen for the sound of propellers and delay surfacing until satisfied that there is no obstruction. On the surface, the diver should scan immediately in all directions and check the location of the support craft, other divers, and any approaching surface traffic. If they are not seen by the support craft, they should attempt to signal the support craft with hand signals, whistle, or flare.

On the surface, the divers can rest while waiting to be picked up. For buoyancy, life vests or bouyancy compensators can be inflated orally or the diver can use a snorkel for breathing.

As the divers break the surface, the tender and other personnel in the support craft must keep them in sight constantly and be alert particularly for any signs of trouble. While one diver is being taken aboard the support craft, attention must not be diverted from the divers remaining in the water. The dive is completed when all divers are safely aboard.

Usually, getting into the boat will be easier if the divers remove the weight belts and SCUBA and then hand them to the tenders. If the boat has a ladder, swim fins should also be removed. Without a ladder, the swim fins will help to give him an extra push to get aboard. A small boat may be boarded over the side or over the stern depending on the type of craft and the surface conditions. As each diver comes aboard a small boat or a raft, other personnel in the boat should remain seated.

5-4.10 Postdive Procedures. The Diving Supervisor should debrief each returning diver while the experience of the dive is still fresh. The Diving Supervisor should determine if the assigned tasks were completed, if any problems were encountered, if any changes to the overall dive plan are indicated, and if the divers have any suggestions for the next team.

When satisfied with their physical condition, the divers' first responsibility after the dive is to check their equipment for damage and get it properly cleaned and stowed.

Each diver is responsible for the immediate postdive maintenance and proper disposition of the equipment used during the dive. The Planned Maintenance System provides direction for postdive maintenance.

CHAPTER SIX

SURFACE-SUPPLIED AIR DIVING OPERATIONS

6-1 INTRODUCTION

Surface-supplied air diving includes those forms of diving in which air is supplied from the surface to the diver by a flexible hose. Surface-supplied diving operations are generally classified as either deep-sea or lightweight, and use equipment specifically developed for these operations. The Navy deep-sea diving outfit, MK 12 Surface Supplied Diving System (SSDS), is used primarily for operations to 190 feet of seawater (fsw) or when the diver needs a high degree of protection. At shallower depths or when a lesser degree of protection is needed, lightweight diving systems, such as the UBA MK 21 MOD 1 SSDS or the UBA MK 20 MOD 0, are used. The advantages and disadvantages of the various types of diving outfits are discussed in detail in Chapter 4.

The information in this chapter includes:

- Surface-supplied air diving equipment
- Surface air supply systems
- Diver communications
- Underwater techniques and procedures

6-2 MK 12 SURFACE SUPPLIED DIVING SYSTEM (SSDS)

6-2.1 System Description. The MK 12 SSDS (Figure 6-1) is intended primarily for operations to 190 fsw in the air mode. Its design features diver mobility and comfort, a wide field of view, reduced noise level, reduced system weight, reduced possibility of diver blowup, and a high degree of safety. The MK 12 SSDS also provides physical and thermal protection and con-

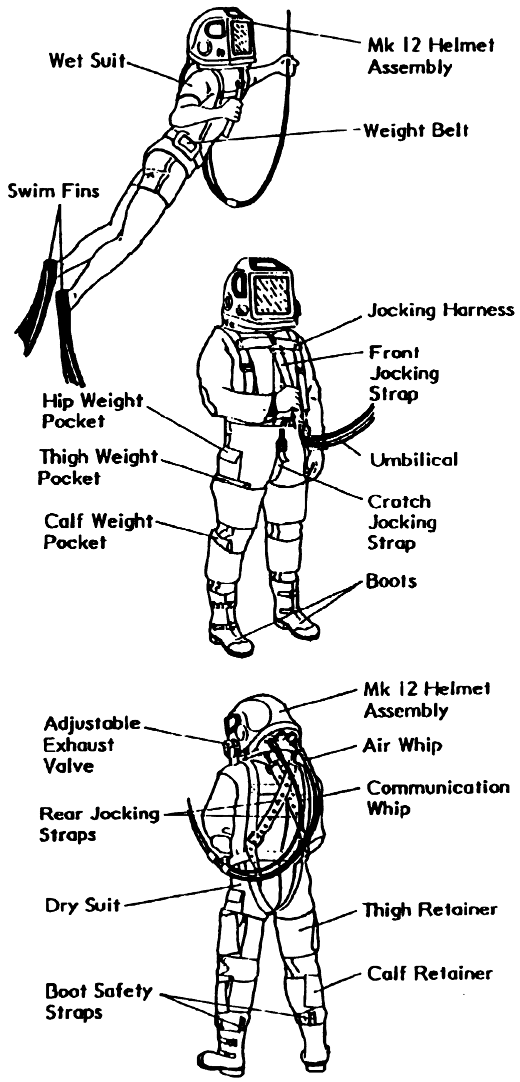


Figure 6-1. Surface-Support Diving System (SSDS) MK 12.

stant, two-way communications with the surface and other divers. The MK 12 SSDS is the only approved rig for contaminated water diving.

NAVSEA 0994-LP-018-5010 Technical Manual, *Operation & Maintenance Instructions Surface Support Diving System (SSDS) Mk 12* is the manual for the MK 12 system.

6-2.2 Air Supply Requirements. The MK 12 SSDS is designed for compatibility with existing fleet equipment, which includes the diving console and umbilicals. In the normal air configuration (with a dry suit, Figure 6-2), the operating range of the exhaust valve provides an internal helmet pressure range from 0.3 to 2.0 psi over ambient pressure at a rate of flow of 6 actual cubic feet per minute (acfm). In the swimmer configuration (used with a neckdam and a wet/swim suit, Figure 6-3), the exhaust valve is modified to provide a fixed helmet pressure of 0.125 psi over ambient pressure at 6 acfm.

6-2.2.1 Flow Requirements. The MK 12 SSDS requires a constant gas flow to prevent excessive accumulation of metabolically produced carbon dioxide (Table 6-1). The actual level of helmet carbon dioxide increases with work rate, but should not exceed two percent surface equivalent value (sev). When planning a diving operation, ensure that the primary air supply system is capable of providing an average sustained flow of 4.5 acfm for each diver including the standby diver. In addition, for short durations of heavy work, the air supply system must be capable of providing each diver in the water with a flow of 6 acfm.

For all dives greater than 170 fsw and using a single Quincy 5120 MPAC as primary air source, MK 21 SSDS will be used for standby diver and minimum manifold pressure (MMP) will be set to 220 psig. For dives using a single Quincy 5120 MPAC as primary air source and standby diver with MK 12 SSDS, maximum depth will be limited to 170 fsw.

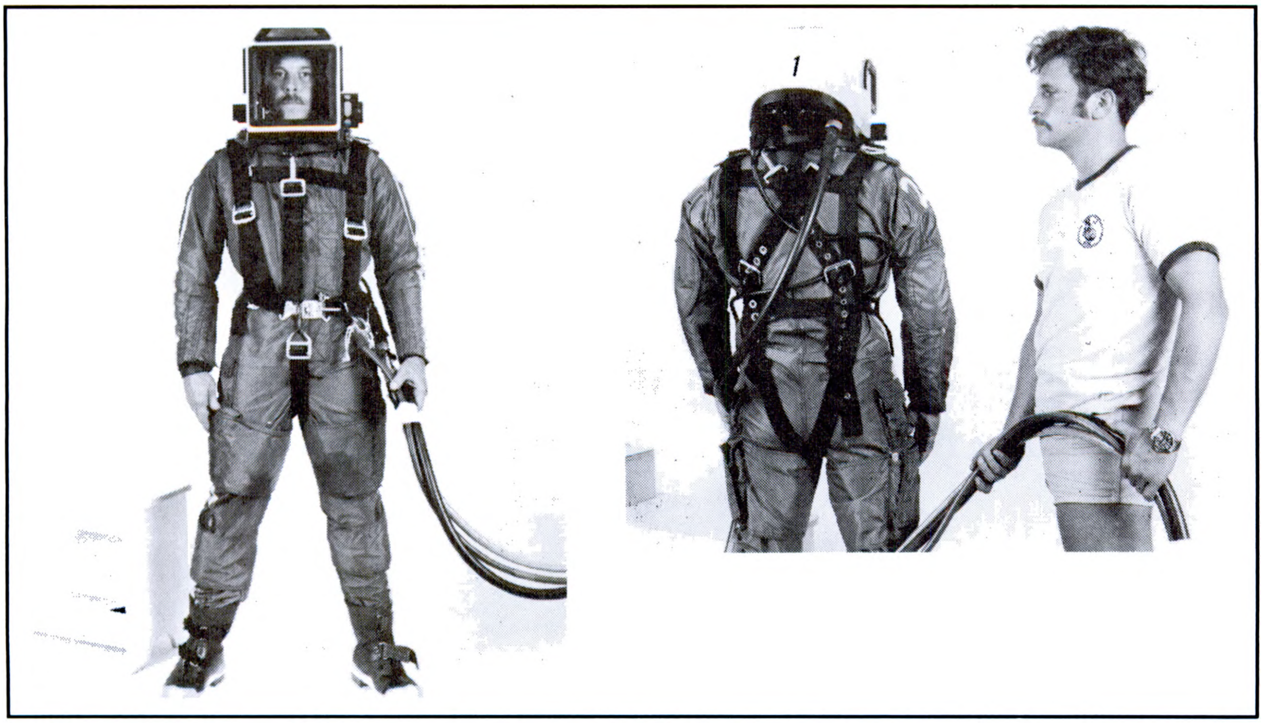


Figure 6-2. Surface-Support Diving System (SSDS) MK 12 Normal Air Configuration.

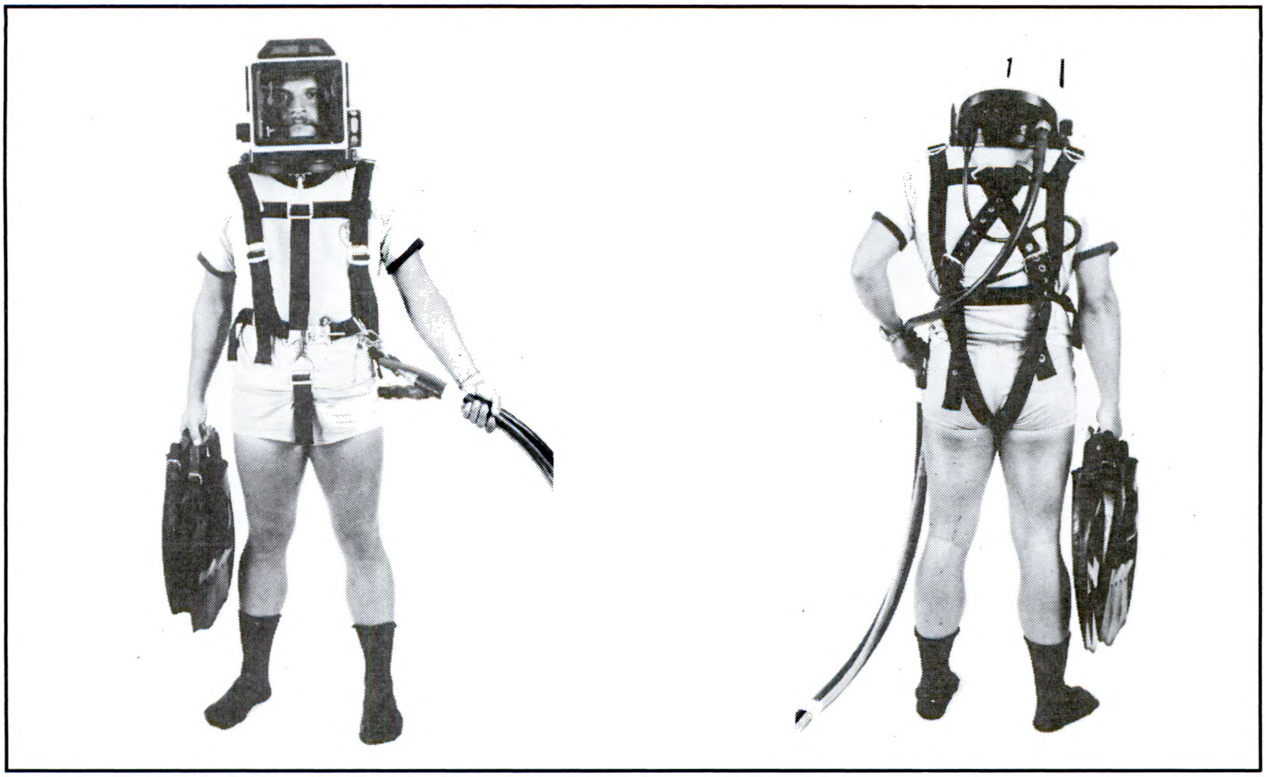


Figure 6-3. MK 12 Helmet in Swimmer (Neckdam) Configuration.

Table 6-1. SSDS MK 12 Flow Requirements.

Condition	Duration	Minimum Flow
Reduced helmet noise (or communications)	Less than 30 sec.	2 acfm
Resting diver during decompression	No-Limit	3 acfm
Moderate to hard work	No-Limit	4.5 afcm
Emergencies	30 sec.	6 acfm

6-2.2.2 Pressure Requirements. Divers' air must be supplied at sufficient pressure to overcome water pressure at depth and pressure losses due to flow through diving hose, fittings, and valves. Operating the MK 12 SSDS with console overbottom pressure determined by hose length and measured airflow ensures satisfactory system operation.

Minimum manifold pressure (MMP) requirements have been formulated to provide for required helmet ventilation. Operating pressure can be derived from the following formulas:

Formulas for minimum manifold pressure (MMP):

Formula 1 (200-foot hose):

MMP (psig) = (diver's depth in fsw x 0.50) + 42

Formula 2 (400-foot hose):

MMP (psig) = (diver's depth in fsw x 0.56) + 42

Formula 3 (600-foot hose):

MMP (psig) = (diver's depth in fsw x 0.62) + 42

6-2.2.3 Sample Calculation.

Example: To determine if air from a high-pressure bank is capable of supporting two MK 12 SSDS divers and one standby diver at a depth of 165 fsw for 25 minutes using a 600-foot umbilical, follow steps 1 through 5 below.

NOTE

Even though 6 acfm (Table 6-1) is required to support a surface-supplied air diver working hard for short durations, calculations to determine total dive consumption requirements are computed using 4.5 acfm.

Solution:

Step 1. Establish parameters of air system:

Number of flasks = 7

Number of flasks on the line = 6

Capacity of flasks = 8 cubic feet floodable volume (cffv)

Flask pressure = 3,000 psig

Depth of dive = 165 fsw

Total bottom time = 25 minutes

Step 2. Calculate minimum manifold pressure (MMP) for the 600-foot umbilical using Formula 3 at 165 fsw.

MMP (psig) = (diver's depth in fsw x 0.62) + 42

= (165 x 0.62) + 42

= 144.3 psig

Round up to 145 psig

Step 3. Calculate standard cubic feet (scf) of air available for use using the following equation.

$$scf\ available = \frac{P_f - (P_{mf} + MMP) \times V \times N}{14.7}$$

Where:

P_f = *Flask pressure = 3,000 psig*

P_{mf} = *Minimum flask pressure = 220 psig*

MMP = Minimum manifold pressure

= 145 psig

NOTE

Pmf is added to provide driving force for the manifold reducer.

V = Capacity of flasks = 8 cffv

N = Number of flasks = 6

$$scf\ available = \frac{3{,}000 - (220 + 145) \times 8 \times 6}{14.7}$$

=8,604 scf

Step 4. Using the Navy Standard Air Decompression Table (Chapter 7), calculate scf of air required to make the dive. 165 feet for 25 minutes requires the following decompression stops from the 170 feet for 25 minutes schedule:

2 minutes at 30 feet

7 minutes at 20 feet

23 minutes at 10 feet

And 3 minutes ascent time (rounded up from 2 minutes 45 seconds) from bottom to surface at 60 fpm. (165 ft/60 fpm = 2 minutes 45 seconds).

Use the following equation to solve for scf required at each decompression stop.

$$scf\ required = \frac{D + 33}{33} \times V \times N \times T$$

Where:

D = Depth (feet)

V = acfm needed per diver

N = Number of divers

T = Time at depth (minutes)

Bottom:

$$scf\ required = \frac{165 + 33}{33} \times 4.5 \times 3 \times 25$$

= 2,025 scf

30-foot stop:

$$scf\ required = \frac{30 + 33}{33} \times 4.5 \times 3 \times 2$$

= 51.54 scf

20-foot stop:

$$scf\ required = \frac{20 + 33}{33} \times 4.5 \times 3 \times 7$$

= 151.77 scf

10-foot stop:

$$scf\ required = \frac{10 + 33}{33} \times 4.5 \times 3 \times 23$$

= 404.59 scf

Bottom to surface:

$$Average\ depth = \frac{165\,ft}{2}$$

= 82.5 ft

$$scf\ required = \frac{82.5 + 33}{33} \times 4.5 \times 3 \times 3*$$

= 141.75 scf

** Note: rounded up from 2 minutes 45 seconds.*

Total scf required = 2,025 + 51.54 + 151.77 + 404.59 + 141.75

= 2,774.65 scf

Round up to 2,775 scf total air required.

Step 5. To determine if there is sufficient air available to make this dive use the following equation.

air remaining = scf available for use

- scf required

= 8,604 scf - 2,775 scf

= 5,829 scf

Since approximately 5,800 scf would remain after the dive, more than sufficient air is available to make this dive.

NOTE

There may be a difference between planned air use and actual air use. A standby diver must be considered for all diving operations. The Diving Supervisor must note initial air volume/pressure and continue to monitor consumption throughout the dive. Should consumption exceed that which is planned, the Diving Supervisor may be required to terminate the dive early in order to ensure there is adequate air remaining in the primary air supply to complete decompression.

6-3 UBA MK 21 MOD 1 SSDS

6-3.1 System Description. The UBA MK 21 MOD 1 SSDS is an open-circuit, demand, lightweight diving helmet (Figure 6-4). For the advantages and disadvantages of lightweight diving equipment, see Chapter 4 of this volume. NAVSEA S6560-AG-OMP-010-UBA-21/1, *Technical Manual, Operation and Maintenance Instructions, Underwater Breathing Apparatus MK 21 MOD 1 Surface-Supported Diving System* is the technical manual for the MK 21 MOD 1 equipment. To ensure safe and reliable service, the MK 21 MOD 1 system must be maintained and repaired in accordance with PMS procedures and the MK 21 MOD 1 operation and maintenance manual.

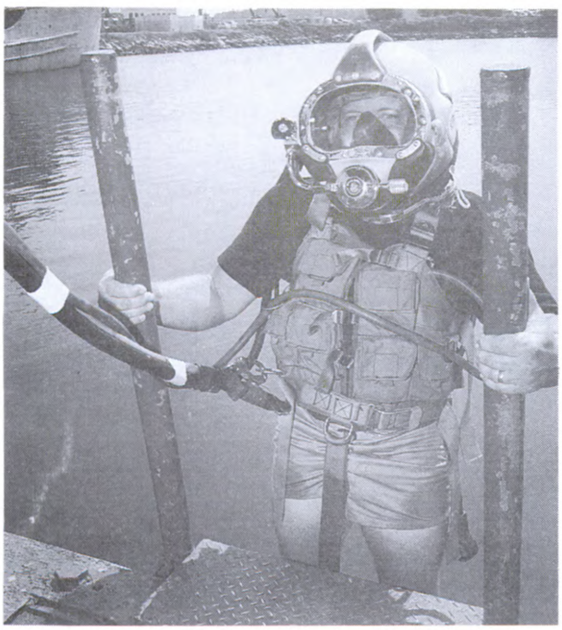


Figure 6-4. MK 21 MOD 1 SSDS.

When using the MK 21 MOD 1 system for air diving operations, the maximum working depth is 190 fsw. The MK 21 MOD 1 system may be used from zero to 60 feet without an emergency gas supply (EGS). Use of an EGS is mandatory at depths from 60 fsw to 190 fsw and when diving inside a wreck. The Diving Supervisor may elect to use an EGS which can be man-carried or located outside the wreck and connected to the diver with a 150-foot whip. Planned air dives below 190 fsw require CNO approval.

6-3.2 Air Supply. Air for the MK 21 MOD 1 system is supplied from the surface by either an air compressor or a bank of high-pressure air flasks as described in Paragraph 6-9.

- **Emergency Air Supply -** The emergency breathing supply valve provides an air supply path parallel to the nonreturn valve. This valve permits attachment of the EGS whip. The EGS system consists of a 72 cubic-foot (minimum) SCUBA bottle and a first-stage regulator, which is set at 135 ±5 psi over bottom pressure. A relief valve set at 180 - 185 psi over bottom pressure must be installed on the first-stage regulator to prevent rupture of the low pressure hose should the first-stage regulator fail. The flexible low-pressure hose from the first-stage regulator attaches to the emergency supply valve on the helmet sideblock. A submersible tank pressure gauge is also required on the first-stage regulator.

6-3.2.1 Flow Requirements. When the MK 21 MOD 1 system is used, the air supply system must be capable of providing an average sustained flow of 1.4 acfm to the diver and for short periods of heavy work a flow of 3.2 acfm. Observation shows that air consumption of divers using the MK 21 MOD 1 varies between 0.75 and 1.5 acfm when used in a demand mode, with occasional faceplate and mask clearing. When used in a free-flow mode, greater than eight acfm is consumed.

NOTE

Although 3.2 acfm is required for short durations, when planning a dive, calculations are based on 1.4 acfm.

The air supply must meet three criteria to satisfactorily support the MK 21 MOD 1 system: (1) it must replenish the air consumed from the system (average rate of flow); (2) it must replenish the air at a rate sufficient to maintain the required pressure; and (3) the system of volume tank, pressure regulators, piping, filters, etc., must provide the maximum rate of flow required by the diver.

6-3.2.2 Pressure Requirements. Because the MK 21 MOD 1 helmet is a demand type system, the regulator has an optimum overbottom pressure which ensures the lowest possible breathing resistance and reduces the possibility of overbreathing the helmet (demanding more air than is available). The manifold supply pressure requirement is 90 psig over bottom pressure for depths to 60 fsw, and 135 psig over bottom pressure for depths over 60 fsw. This ensures that the air supply will deliver air at a pressure sufficient to overcome bottom seawater pressure and the pressure drop which occurs as the air flows through the hoses and valves of the mask.

6-3.2.3 Sample Calculation.

Example: In determining the air supply manifold pressure required to dive the MK 21 MOD 1 system to 175 fsw, follow the steps below.

Solution: Bottom pressure at 175 fsw = 77.87 psig (round off to 78 psig). Required overbottom pressure for MK 21 MOD 1 system = 135 psig. Minimum manifold pressure = 78 psig + 135 psig = 213 psig. Minimum manifold pressure for 175-fsw dive must be 213 psig.

Example: In determining if air from a bank of high-pressure flasks is capable of supporting two MK 21 MOD 1 divers and one standby diver at a depth of 130 fsw for 30 minutes, follow the steps below.

NOTE

These calculations are based on an assumption of an average of 1.4 acfm diver air consumption over the total time of the dive. Higher consumptions over short periods can be expected based on diver work rate.

Solution:

Step 1. Establish parameters of air system:

Number of flasks = 5

Number of flasks on line = 4

Capacity of flasks = 8 cubic feet floodable volume (cffv)

Flask pressure = 3,000 psig

Depth of dive = 130 feet

Total bottom time = 30 minutes

Step 2. Calculate minimum manifold pressure (MMP).

MMP (psig) = (0.445D) + 135 psig

= (0.445 x 130) + 135 psig

= 192.85 psig

Round up to 193 psig

Step 3. Calculate standard cubic feet (scf) of air available using the following equation.

$$scf\ available = \frac{P_f - (P_{mf} + MMP)}{14.7} \times V \times N$$

Where:

P_f = *Flask pressure = 3,000 psig*

P_{mf} = *Minimum flask pressure = 220 psig*

MMP = Minimum manifold pressure

= 193 psig

V = Capacity of flasks = 8 cffv

N = Number of flasks = 4

$$scf\ available = \frac{3{,}000 - (220 + 193)}{14.7} \times 8 \times 4$$

= 5,631 scf

Step 4. Calculate scf of air required to make the dive. A dive to 130 fsw for 30 minutes requires the following decompression stops:

3 minutes at 20 feet

18 minutes at 10 feet

Plus 3 minutes ascent time (rounded up from 2 minutes 10 seconds) from 130 feet to the surface at 60 feet per minute.

Use the following equation to solve for scf required at each decompression stop.

$$\text{scf required} = \frac{D + 33}{33} \times V \times N \times T$$

Where:D = Depth (feet)

V = acfm needed per diver

N = Number of divers

T = Time at depth (minutes)

Bottom:

$$scf\ required = \frac{130 + 33}{33} \times 1.4 \times 3 \times 30$$

= 622.37 scf

20-foot stop:

$$scf\ required = \frac{20 + 33}{33} \times 1.4 \times 3 \times 3$$

= 20.24 scf

10-foot stop:

$$scf\ required = \frac{10 + 33}{33} \times 1.4 \times 3 \times 18$$

= 98.51 scf

130 feet to surface (ascent):

$$Average\ depth = \frac{130}{2} = 65\ feet$$

$$scf\ required = \frac{65 + 33}{33} \times 1.4\ 3 \times 3*$$

= 37.42 scf

** Note: rounded up from 2 minutes 10 seconds.*

622.37 + 20.24 + 98.51 + 37.42 = 778.54 scf

Round up to 779 scf total required.

Step 5. 5,631 scf available - 779 scf required = 4,852 scf remaining. More than sufficient air is available in the air supply flasks to make this dive.

NOTE

Planned air usage estimates will vary from actual air usage. The air requirements for a standby diver must also be taken into account for all diving operations, and maximum gas flow requirements must be assumed. The Diving Supervisor must note initial volume/pressure and continue to monitor consumption throughout dive. If actual consumption exceeds planned consumption, the Diving Supervisor may be required to curtail the dive in order to ensure there is adequate air remaining in the primary air supply to complete decompression.

6-4 UNDERWATER BREATHING APPARATUS (UBA) MK 20 MOD 0

The Underwater Breathing Apparatus (UBA)

MK 20 MOD 0 is a lightweight, surface-supplied air system for use in enclosed spaces, such as submarine ballast tanks. The MK 20 MOD 0 is authorized for use to a depth of 60 feet with surface-supplied air. MK 20 MOD 0 safety considerations and working procedures are covered in Chapter 4 of this dive manual.

6-4.1 System Description. MK 20 MOD 0 diver-worn equipment consists of a full face mask, diver communications components, equipment harness, and an umbilical assembly (Figure 6-5).

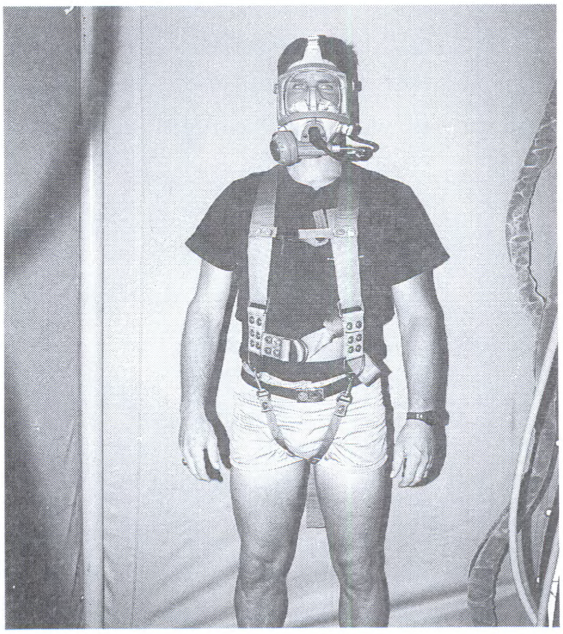


Figure 6-5. MK 20 MOD 0 UBA.

The mask body provides the framework for mounting the inner oral-nasal mask, demand regulator, and microphone. The MK 20 MOD 0 face mask is made of molded rubber and is fitted with a wide-view polycarbonate visor. The oral-nasal mask, also molded of rubber, minimizes dead space within the mask.

The demand regulator functions only on inhalation and contains separate inhalation and exhalation channels to ensure that inhalation and exhalation air do not mix. The regulator valve provides a slight positive pressure in the mask which is maintained throughout the breathing cycle, and reduces the risk of water leakage. A balance feature in the valve maintains low breathing resistance despite variations in air delivery pressure that may occur in connection with surface-supplied diving.

The communication system components are compatible with diver communication units currently in service. The system includes a conferencing capability that enables divers to communicate with each other and with topside personnel at the same time. MK 20 MOD 0 provides the diver with a microphone, bone-conducting earphone, and a communication whip. The microphone is waterproof and preamplified, and it includes a noise-cancelling capability that reduces the transmission of background noise.

The harness secures and distributes the weight of diver-worn equipment and provides a strain-relief for the umbilical.

The umbilical consists of an air supply hose, a pneumofathometer hose, a strength cable, and a communication cable. Either a 3/8-inch or a 1/2-inch air supply hose may be used. A canvas chafing sheath is sewn or secured with velcro over 50 feet of the umbilical at the diver's end.

6-4.2 Air Supply. MK 20 MOD 0 requires a breathing gas flow of 1.4 acfm and an overbottom pressure of 90 psi. Flow and pressure requirement calculations are similar to those described in Paragraph 6-3.2.3 for MK 21 MOD 1.

6-4.3 Emergency Gas Supply Requirements for MK 20 MOD 0. In order to ensure a positive emergency air supply to the diver when working in a ballast tank, mud tank, or confined space, an emergency gas supply (EGS) assembly must be used. As a minimum, the EGS assembly will consist of:

- Single SCUBA cylinder (minimum 71.2 cubic feet) with either a K or J valve, charged to a minimum of 1,800 psi

- An approved SCUBA regulator set at 150 psi over bottom, with an extended EGS whip up to 150 feet in length.

- An approved Seaview gauge.

The SCUBA cylinder is left on the surface and the EGS whip may be married to the diver's umbilical. The diver may then enter the work space with the extended EGS whip trailing. The second-stage regulator of the EGS is securely attached to the diver's harness before entering the work space so that the diver has immediate access to the EGS regulator in an emergency.

6-5 PORTABLE SURFACE-SUPPLIED DIVE SYSTEMS

The U.S. Navy has four unique, surface-supplied, transportable diving systems. The Ready Operational Pierside Emergency Repair (ROPER) cart is designed principally for pierside underwater ship husbandry while the Flyaway Air Dive Systems (FADS) I and II are intended for use from a vessel of opportunity. The latest system is the MK III Lightweight Dive System.

6-5.1 ROPER Diving Cart. The ROPER diving cart (Figure 6-6) is a trailer-mounted diving system, designed to support one working and one standby diver in underwater operational tasks performed by Ship Repair Activities to 60 fsw. The system is self-contained, transportable, and certifiable in accordance with *U.S. Navy Diving and Manned Hyperbaric System Safety Certification Manual*, NAVSEA SS521-AA-MAN-010.

The major components/subsystems mounted within the cart body are:

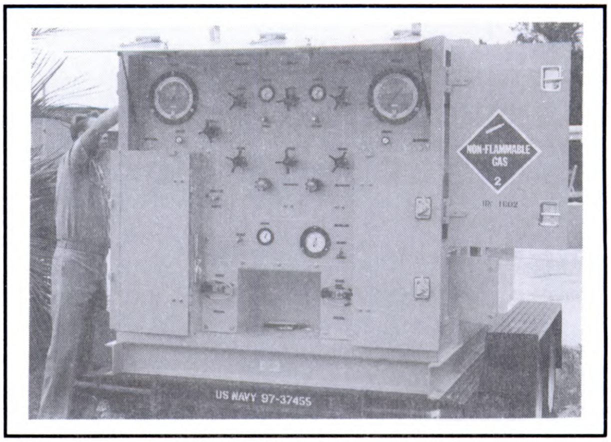


Figure 6-6. ROPER Diving Cart.

- **Diving control station -** A single operator controls and monitors the air supply and operates the communication system.

- **Power distribution system -** External power for communications and control station lighting.

- **Intercommunication system (AC/DC) -** Provides communications between divers and the diving control station.

- **Air supply system -** Primary air source of two 6-cubic-foot, 3,000-psi air flasks; secondary air source of a single 1.52-cubic-foot, 3,000-psi air flask; and a SCUBA charging station.

Detailed information and operating instructions are covered in *Operations and Maintenance Instructions For Ready Operational Pierside Emergency Repair (ROPER) Diving Cart*, SS500-AS-MMA-010.

6-5.2 FADS I. The FADS I (Figure 6-7) is an air transportable, 0-190 fsw, system that can be delivered to a suitable diving platform quickly. The system consists of a filter control console (FCC) intended for use with the medium-pressure flyaway air compressors and/or conventional air supplies. In its present configuration, the system can service up to four divers depend-

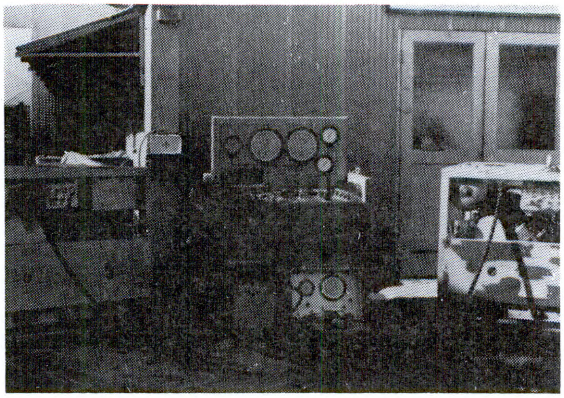


Figure 6-7. Flyaway Air Dive System I (FADS 1).

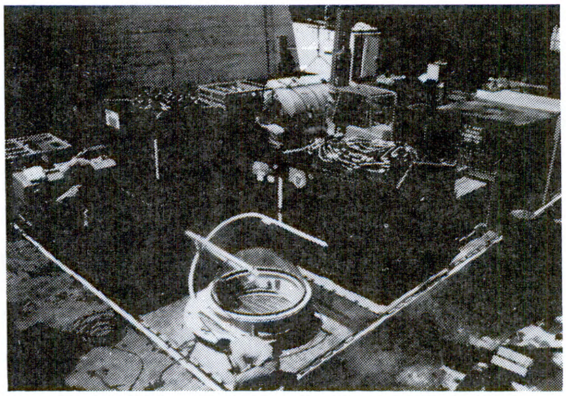


Figure 6-8. Flyaway Air Dive System II (FADS II).

ing on the diving equipment in use. The MK 12 or the MK 21 MOD 1 equipment may be employed with the FADS I.

Operation instructions for FADS I and II are covered in *Fly Away Diving System Filter/Control Console Operation and Maintenance Instructions, S9592-AD-MMM/FLTR CONT CSL*; *Fly Away Diving System Compressor Model 5120 Operation and Maintenance Instructions, S9592-AE-MMM-010/MOD 5120*; and *Fly Away Diving System Diesel Driven Compressor Unit Ex 32 Mod 0, PN 5020559, Operation and Maintenance Instructions, S9592-AC-MMM-010/Detroit DSL 3-53.*

6-5.3 FADS II. The FADS II (Figure 6-8) is a self-supported, air transportable, 0-190 fsw air diving system, designed and packaged for rapid deployment worldwide to a vessel of opportunity. Primarily intended for use in recovery of salvageable objects or inspection and emergency ship repairs, the system's main components are:

- **Lightweight diving outfit -** Four demand helmet (MK 21 MOD 1) assemblies with umbilicals, communication system, tool kit, and repair parts kit.
- **MK 12 SSDS -** MK 12 helmet assembly, dress assembly, and support equipment for three divers (two working and one standby).
- **Two medium-pressure air compressors (MPAC) -** Diesel-driven QUINCY 250 psi, 87 standard cubic feet per minute (scfm), skid-mounted.
- **High-pressure air compressor (HPAC) -** Diesel-driven INGERSOLL RAND 10T2, 3,000 psi, 15 scfm, skid-mounted.
- **Filter control console -** Regulates and filters air from MPAC, HPAC, or HP banks to support four divers, skid-mounted.
- **Suitcase filter control console -** Filters MPAC air to support three divers.
- **Double-lock aluminum recompression chamber -** Standard USN chamber, skid-mounted and designed to interface with filter control console.
- **Two HP air banks -** Two sets of HP banks providing additional secondary diver and chamber air.
- **HP oxygen bank -** One bank of HP oxygen providing chamber support.

- **5 kW diesel generator -** Provides power for communications, chamber lighting, miscellaneous.

- **5 kW diesel light tower -** Provides power to tripod lights, mast lights, underwater lights.

- **Hydraulic tool package and underwater lights -** As required.

- **Equipment shelter -** Fiberglass container houses filter control console and diving station.

- **Two conex boxes -** Steel containers for equipment storage.

6-5.4 MK III Lightweight Diving System (LWDS). The LWDS is an easily handled and transported, self-contained diver life support system. It is intended to provide working divers in shallow water with clean, surface-supplied air. The system is certified for two working divers and a standby diver to a depth of 60 fsw, (in the LP mode) and to 130 fsw (in the HP mode) at a moderately heavy work rate of 62.5 liters per minute (lpm) Respiratory Minute Volume (RMV) for a six-hour mission. The system is designed for use in the following configurations:

a. **Configuration 1 -** Diesel-compressor unit supplying primary diver air supply at 18 standard cubic feet per minute (scfm) with secondary air being supplied by three high pressure (HP) composite flasks.

b. **Configuration 2 -** Nine HP composite flasks (three racks of three flasks each) supplying primary air with secondary air being supplied by three HP composite flasks.

6-6 ACCESSORY EQUIPMENT FOR SURFACE-SUPPLIED DIVING

Accessory equipment which is often useful in surface-supplied diving operations includes:

- **Lead line -** For measuring depth.

- **Descent line -** To guide the diver to the bottom and for use in passing tools and equipment. This three-inch line is double braid to prevent twisting and to facilitate easy identification by the diver on the bottom. In use, the end of the line may be fastened to a fixed underwater object, or it may be anchored with a weight heavy enough to withstand the current.

- **Circling line -** The circling line is attached to the bottom end of the descent line. It is used by the diver as a guide in searching and for relocating the descent line.

- **Stage -** Constructed to carry one or more divers, it is used both for putting divers into the water and for bringing them to the surface, especially when decompression stops must be made. The stage platform is made in an open grillwork pattern to reduce resistance from the water and may include seats. Guides for the descent line, several eyebolts for attaching tools, and steadying lines or weights are provided. The frames of the stages may be collapsible for easy storage. A safety shackle or screw-pin shackle siezed with wire must be used to connect the stage to the lifting line when raising or lowering. Stages must be weight tested in accordance with PMS.

- **Stage line -** Used for raising and lowering the stage, is to be 3-inch double braid, or 3/8- or 7/16-inch wire rope, taken to a capstan or run off a winch and davit.

- **Diving ladder -** Used for entering the water from a vessel.

- **Cast iron weights -** Provided in two sizes: 50- and 100-pound clumps. Both sizes are used as descent line weights.

- **Canvas toolbag -** Used for carrying tools.

- **Stopwatches -** Used for timing the total dive time, decompression stop time, travel time, etc.

6-7 SURFACE AIR SUPPLY SYSTEMS

The diver's air supply may originate from an air compressor, a bank of high-pressure air, or a combination of both.

6-7.1 Requirements for Air Supply.
Regardless of the source, the air must meet certain established standards of purity (Appendix L), must be supplied in an adequate volume for breathing, and must have a rate of flow which will properly ventilate the helmet or mask. The air must also be provided at sufficient pressure to overcome the bottom water pressure and the pressure losses due to flow through the diving hose, fittings, and valves. The air supply requirements depend upon specific factors of each dive such as depth, duration, level of work, number of divers being supported, and type of diving system being used.

6-7.1.1 Air Purity Standards. If taken directly from the atmosphere and pumped to the diver, air may not meet established purity standards. It may be contaminated by engine exhaust or chemical smog. Initially pure air may become contaminated while passing through a faulty air compressor system. For this reason, all divers' air must be periodically sampled and analyzed to ensure the air meets purity standards (Appendix L). The quality of the air of any supply system must conform to the following limits:

- Oxygen concentration=20-22% by volume

- Carbon dioxide=1,000 ppm maximum

- Carbon monoxide=20 ppm maximum

- Total hydrocarbons other than methane * =25 ppm maximum

  * During normal gas analysis, hydrocarbons are first converted to methane and analyzed. The actual methane value is then subtracted from this result to give the value for the unknown hydrocarbons. Unknown hydrocarbons should not exceed 25 ppm.

- Particulates and oil mist = 5 mg/m^3 maximum

- Odor or taste=Not objectionable

To meet these standards, specially designed water-lubricated compressors must be used, or the air supplied by a standard compressor must be passed through a highly efficient filtration system. The compressed air found in a shipboard service system usually contains excessive amounts of oil and is not suitable for diving unless filtered. Air taken from any machinery space, or downwind from the exhaust of an engine or boiler, must be considered to be contaminated. For this reason, care must be exercised in the placement and operation of diving air compressors to avoid such conditions. Intake piping or ducting must be provided to bring uncontaminated air to the compressor. The outboard end of this piping must be positioned to eliminate sources of contamination. To ensure that the source of diver's breathing air, whether a compressor or HP bank, satisfactorily meets the standards established above, it must be checked at intervals not to exceed six months (as described in Appendix I) in accordance with the PMS.

6-7.1.2 Air Supply Flow Requirements. The required flow from an air supply depends upon the type of diving apparatus being used. If the air supply system is to be used in conjunction with open-circuit, steady flow apparatus, such as the MK 12 SSDS, flow must be adequate to meet the requirements of ventilation. The open-circuit air supply system must have a flow capacity (in acfm) which provides sufficient ventilation at depth to maintain low carbon dioxide levels in the mask or helmet. Carbon dioxide levels must be kept within safe limits at all times (normal work, heavy work, and emergencies).

If demand breathing equipment is used, such as the MK 21 MOD 1 or the MK 20 MOD 0, the supply system must meet the diver's flow requirements. The flow requirements for respiration in a demand system are based upon the average rate of air flow demanded by the divers under normal working conditions. The maximum instantaneous (peak) rate of flow under severe work conditions is not a continuous requirement, but rather the highest rate of airflow attained during the inhalation part of the breathing cycle. The diver's requirement varies with the respiratory demands of the diver's work level.

6-7.1.3 Supply Pressure Requirements. In order to supply the diver with an adequate flow of air, the air source must deliver air at sufficient pressure to overcome the bottom seawater pressure, and the pressure drop which will be introduced as the air flows through the hoses and valves of the system. Values for air consumption and minimum over bottom pressures required for each of the surface-supplied air diving systems are presented in Table 6-2.

6-7.1.4 Water Vapor. A properly operated air supply system should never permit the air supplied to the diver to reach its dewpoint. Controlling the amount of water vapor (humidity) in the supplied air is normally accomplished by one or both of the following methods.

- **Compression/expansion -** As high-pressure air expands across a pressure reducing valve, the partial pressure of the water vapor in the air is decreased. Since the expansion takes place at essentially a constant temperature (isothermal), the partial pressure of water vapor required to saturate the air remains unchanged. Therefore, the relative humidity of the air is reduced.

- **Cooling -** Cooling the air prior to expanding it raises its relative humidity, permitting some of the water to condense. The condensed liquid may then be drained from the system.

6-7.1.5 Standby Diver Air Requirements. Air supply requirements cannot be based solely on the calculated continuing needs of the divers who are initially engaged in the operation. There must be an adequate reserve to support a standby diver should one be needed.

6-7.2 Primary and Secondary Air Supply. All surface-supplied diving systems must include a primary and a secondary air supply in accordance with the *U.S. Navy Diving and Manned Hyperbaric Systems Safety Certification Manual*, SS521-AA-MAN-010. The primary supply must be able to support the air flow and pressure requirements for the diving equipment designated (Table 6-2). The capacity of the primary supply must be such that it will meet the consumption rate of the designated number of divers for the full duration of the dive (bottom time plus decompression time). The maximum depth of the dive, the number of divers, and the equipment to be used must be taken into account when sizing the supply. The secondary supply must be sized to be able to support recovery of all divers using the equipment and dive profile of the primary supply if the primary supply sustains a casualty at the worst case time (for

Table 6-2. Primary Air System Requirements.

System	Minimum Manifold Pressure (Pm)	Air Consumption: Average Over Period of Dive (acfm)	Air Consumption: Short Duration (30 Sec.) Heavy/Emergency Requirements (acfm)
SSDS MK 12	Formula for 200' hose: (Depth in fsw x 0.50) + 42	4.5	6.0
	Formula for 400' hose: (Depth in fsw x 0.56) + 42	4.5	6.0
	Formula for 600' hose: (Depth in fsw x 0.62) + 42	4.5	6.0
MK 21 MOD 1 Mask	(Depth in fsw x 0.445) + 135	1.4	3.2 (Note 1)
MK 20 MOD 0	(Depth in fsw x 0.445) + 135	1.4	3.2 (Note 2)
Note 1:	The MK 21 MOD 0 diver, in the demand mode, can consume up to 3.32 acfm while performing severe work. The mask will allow 8.0 acfm to free-flow when the valve is fully open.		
Note 2:	The MK 20 MOD 0 diver steady flow can consume up to 3.2 acfm while performing severe work. If allowed to free-flow, the mask will deliver a minimum of 10 acfm.		

example, immediately prior to completion of planned bottom time of maximum dive depth, when decompression obligation is greatest). Primary and secondary supplies may be either high-pressure (HP) bank-supplied or compressor-supplied.

Operating procedures (OPs) and emergency procedures (EPs) must be available to support operation of the system and recovery from emergency situations. OPs and EPs are required to be NAVSEA approved in accordance with Appendix N. Should the surface-supplied diving system be integrated with a recompression chamber, an air supply allowance for chamber requirements (Appendix D) must be made.

All valves and electrical switches which directly influence the air supply shall be labeled:

"DIVER'S AIR SUPPLY - DO NOT TOUCH"

Banks of flasks and groups of valves require only one central label at the main stop valve.

A volume tank must be part of the air supply system and be located between the supply source and the diver's manifold hose connection. This tank serves to maintain the air supply should the primary supply source fail, providing time to actuate the secondary air supply and serve to attenuate the peak air flow demand.

6-7.2.1 Air Compressors. Many air supply systems used in Navy diving operations include at least one air compressor as a source of air. To properly select such a compressor, it is essential that the diver have a basic understanding of the principles of gas compression. Guidance is contained in NAVSEAINST 10560.2 (series) for Navy approved compressors for divers' air systems.

Reciprocating air compressors are the only compressors authorized for use in Navy air diving operations. Low-pressure (LP) models are capable of providing rates of flow sufficient to support surface-supplied air diving or recompression chamber operations. High-pressure models are capable of charging high pressure air banks and SCUBA cylinders.

An air compressor must be selected which will meet the flow and pressure requirements outlined in Paragraphs 6-7.1.2 and 6-7.1.3. Normally, reciprocating compressors have their rating (capacity in cfm and delivery pressure in psig) stamped on the manufacturer's identification plate. This rating is based on inlet conditions of 70°F (21.1°C), 14.7 psia barometric pressure, and 36 percent relative humidity (an air density of 0.075 pound per cubic foot). If inlet conditions vary, the actual capacity will either increase or decrease from rated values. If not provided directly, capacity may be approximated from the displacement data provided on the compressor or by conducting a compressor output test. Since the capacity is the volume of air at defined atmospheric conditions, compressed per unit of time, it will be affected only by the first stage, as all other stages serve only to increase the pressure and reduce temperature. All industrial compressors are stamped with a code, consisting of at least two, but usually four to five, numbers which specify the bore and stroke, as illustrated in Figure 6-9.

6	x	6	x	4	x	2	x	4
1st stage 1st piston 6" diameter		1st stage 2nd piston 6" diameter		2nd stage 4" diameter		3rd stage 2" diameter		4" stroke

Figure 6-9. Typical Industrial Air Compressor Code.

Using this code, the displacement per revolution of the compressor is equal to the volume of the first-stage cylinder(s).

First Stage Volume:

$$V = \frac{3.14 \times (diameter)^2}{4}\ x\ stroke\ x\ no.\ of\ first\text{-}stage\ cylinders$$

$$= \frac{3.14 \times (6\ in)^2}{4} \times 4\ in \times 2$$

$$= 226\ cubic\ inches\ per\ revolution$$

If the compressor operates at 440 rpm, then the displacement capacity is:

$$V = 226\ in^3/rev \times 440\ rev/\mathrm{min}$$

$$= 99{,}440\ in^3/\mathrm{min}$$

Converting cubic inches per minute to cubic feet per minute:

$$V = \frac{99{,}440\ in^3/\mathrm{min}}{1{,}728\ in^3/ft^3} = 57.5\ cfm$$

The actual capacity of the compressor will always be less than the displacement because of the clearance volume of the cylinders. This is the volume above the piston that does not get displaced by the piston during compression. Compressors having a first-stage piston diameter of four inches or larger will normally have an actual capacity of about 85 percent of their displacement. The smaller the first-stage piston, the lower the percentage capacity will be (because the clearance volume represents a greater precentage of the cylinder volume).

Reciprocating piston compressors are either oil lubricated or water lubricated. The majority of the Navy's diving compressors are oil lubricated. In these compressors the lubricant serves to:

- Prevent wear between friction surfaces
- Seal close clearances
- Protect against corrosion
- Transfer heat and minute particles produced from wear away from points of contact

Unfortunately, this lubricant will vaporize into the air supply, and if not condensed or filtered out, will reach the diver. Lubricants used in air diving compressors must conform to military specifications: MIL-L-17331 (2190 TEP) for normal operations or MIL-H-17672 (2135 TH) for cold weather operations.

Use of an oil-lubricated compressor for diving is contingent upon proper maintenance to limit the amount of oil introduced into the diver's air. When using any lubricated compressor for diving, the air must be checked for oil contamination. Diving operations shall be aborted at the first indication that oil is in the air being delivered to the diver. An immediate analysis must be conducted to determine whether the amount of oil present exceeds the maximum permissible level of five mg per cubic meter for oil mist and particulate, or a hydrocarbon level, other than methane of 25 ppm for oil which is vaporized.

It should be noted that air in the higher stages of a compressor has a greater amount of lubricant injected into it than in the lower stages. It is recommended that the compressor selected for a diving operation provide as close to the required pressure for that operation as possible. A system which provides excessive pressure contributes to the buildup of lubricant in the air supply.

Intercoolers are heat exchangers which are placed between the stages of a compressor to control the air temperature. Water, flowing through the heat exchanger counter to the air flow, serves both to remove heat from the air and to cool the cylinder walls. Intercoolers are frequently air cooled. During the cooling process, water vapor is condensed out of the air into condensate collectors. The condensate must be drained periodically during operation of the compressor, either manually or automatically.

As the air is discharged from the compressor, it passes through a moisture separator and an approved filter to remove lubricant, aerosols, and particulate contamination before it enters the system.

A back-pressure regulator will be installed downstream of the moisture separator and upstream of the first filter. A compressor will only compress air to meet the supply pressure demand. If no demand exists, air will simply be pumped through the compressor at atmospheric pressure. Systems within the compressor, such as the intercoolers, are designed to perform with maximum efficiency at the rated pressure of the compressor. Operating at any pressure below this rating reduces the efficiency of the unit. Additionally, compression reduces water vapor from the air. Reducing the amount of compression increases the amount of water vapor in the air supplied to the diver.

The air supplied from the compressor will expand across the pressure regulator and enter air banks or volume tank. As the pressure builds up in the air banks or volume tank, it will eventually reach the relief pressure of the compressor, at which time the excess air will simply be discharged to the atmosphere. Some electrically-driven compressors are controlled by pressure switches installed in the volume tank or HP flask. When the pressure reaches the upper limit, the electric motor is shut off. When sufficient air has been drawn from the volume tank or HP flask to lower its pressure to some lower limit, the electric motor is restarted.

All piping in the system must be designed to minimize pressure drops. Intake ducting, especially, must be of sufficient diameter so that the rated capacity of the compressor can be fully utilized. All joints and fittings must be checked for leaks using soapy water. Leaks must be repaired. All filters, strainers, and separators must be kept clean. Lubricant, fuel, and coolant levels must be periodically checked.

Any diving air compressor, if not permanently installed, must be firmly secured in place. Most portable compressors are provided with lashing rings for this purpose.

6-7.2.2 High-Pressure Air Cylinders and Flasks. HP air cylinders and flasks are vessels designed to hold air at pressures over 600 psi. Convenient and satisfactory diving air supply systems can be provided by the use of a number of these HP air cylinders or flasks. Any HP vessel to be used as a diving air supply unit must bear appropriate Department of Transportation (DOT) or military symbols certifying that the cylinders or flasks meet high-pressure requirements (see Chapter 5).

A complete air supply system includes the necessary piping and manifolds, HP filter, pressure reducing valve, and a volume tank. An HP gauge must be located ahead of the reducing valve, and an LP gauge must be connected to the volume tank.

In using this type of system, one section must be kept in reserve. The divers take air from the volume tank in which the pressure is regulated to conform to the air supply requirements of the dive. The duration of the dive is limited to the length of time the banks can provide air before being depleted to 220 psi over minimum manifold pressure. This minimum pressure of 220 psi must remain in each flask or cylinder.

As in SCUBA operations, the quantity of air which can be supplied by a system using cylinders or flasks is determined by the initial capacity of the cylinders or flasks and the depth of the dive. The duration of the air supply must be calculated in advance, and must include a provision for decompression.

Sample calculations for dive duration, based on bank air supply, are presented in Paragraph 6-2.2.3 for the MK 12 SSDS, and in Paragraph 6-3.2.3 for the MK 21 MOD 1. The sample problems presented in this chapter do not take the secondary air system requirements into account. The secondary air system must be capable of providing air in the event of failure of the primary system per *U.S. Navy Diving and Manned Hyperbaric Systems Safety Certification Manual*, SS521-AA-MAN-010. In the MK 12 sample problem (Paragraph 6-2.2.3), this would mean decompressing three divers with a 25-minute bottom time using 4.5 acfm per diver. An additional requirement must be considered if the same air system is to support a recompression chamber. It must have the additional capacity required by Appendix D.

6-7.2.3 Shipboard Air Systems. Many Navy ships have permanently installed shipboard air supply systems which provide either LP or HP air. These systems are used in support of diving operations provided they meet the fundamental requirements of purity, capacity, and pressure.

In operation, a volume source (such as a diesel or electrically driven compressor) pumps air into a volume tank. The compressor will automatically keep the tank full as long as the amount of air being used by the diver does not exceed the capacity of the compressor. The ability of a given unit to support a diving operation may be determined from the capacity of the system.

6-8 DIVER COMMUNICATIONS

The surface-supplied diver has two means of communicating with the surface, depending on the type of equipment used. If the diver is using the MK 12 SSDS, the MK 21 MOD 1, or the MK 20 MOD 0, both voice communications and line-pull signals are available. Voice communications are used as the primary means of communication. Line-pull signals are used only as a backup.

Diver-to-diver communications are available through topside intercom, diver-to-diver hand signals, or slate boards.

6-8.1 Diver Intercommunication Systems. The major components of the intercommunication system include the diver's earphones and microphone, the communication cable to each diver, the surface control unit, and the tender's speaker and microphone. The system is equipped with an external power cord and can accept 115 VAC or 12 VDC. The internal battery is used for backup power requirements. It should not be used as the primary power source unless an external power source is not available.

The intercom system is operated by a designated phone talker at the diving station. The phone talker monitors voice communications and keeps an accurate log of significant messages. All persons using the intercom system should lower the pitch of their voices and speak slowly and distinctly. The conversation is kept brief and simple, using standard diving terminology. Divers must repeat verbatim all directions and orders received from topside.

The approved Navy diver communication system is compatible with the MK 12 SSDS, MK 21 MOD 1, and the MK 20 MOD 0. This is a surface/underwater system (Figure 6-10) which

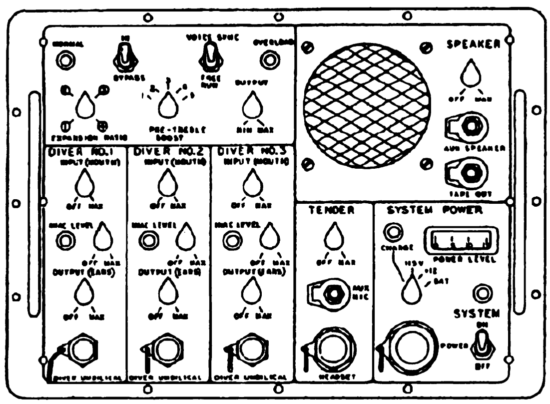


Figure 6-10. Diver's Underwater Communications System (HYDROCOM).

allows conference communications between the tender and up to three divers. It incorporates voice correction circuitry which compensates for the distortion caused by divers speaking in a helium-oxygen atmosphere.

The divers' voices are continuously monitored on the surface. All communications controls are located at the surface. The topside supervisor speaks with any or all of the divers by exercising the controls on the front panel. It is necessary for a phone talker to monitor and control the underwater communications system at all times.

6-8.2 Line-Pull Signals. A line-pull signal consists of one pull or a series of sharp, distinct pulls on the umbilical which are strong enough to be felt by the diver. All slack must be taken out of the line before the signal is given.

The line-pull signal code (Table 6-3) has been established through many years of experience. Standard signals are applicable to all diving operations; special signals may be arranged between the divers and Diving Supervisor to meet particular mission requirements. Most signals are acknowledged as soon as they are received. This acknowledgement consists of replying with the same signal. If a signal is not properly

Table 6-3. Line-Pull Signals.

From Tender to Diver		Searching Signals (Without Circling Line)	
1 Pull	"Are you all right? When diver is descending, one pull means "Stop".	7 Pulls	"Go on (or off) searching signals".
2 Pulls	"Going Down". During ascent, 2 pulls mean "You have come up too far; go back down until we stop you".	1 Pull	"Stop and search where you are".
3 Pulls	"Stand by to come up".	2 Pulls	"Move directly away from the tender if given slack; move toward the tender if strain is taken on the life line".
4 Pulls	"Come up".	3 Pulls	"Face your umbilical, take a strain, move right".
2-1 Pulls	"I understand." or "Talk to me".	4 Pulls	"Face your umbilical, take a strain, move left".
3-2 Pulls	"Ventilate"		
4-3 Pulls	"Circulate"		
From Diver to Tender		**Searching Signals (With Circling Line)**	
1 Pull	"I am al right". When descending, one pull means "Stop" or "I am on the bottom".	7 Pulls	Same
2 Pulls	"Lower" or "Give me slack".	1 Pull	Same
3 Pulls	"Take up my slack".	2 Pulls	"Move away from the weight".
4 Pulls	"Haul me up".	3 Pulls	"Face the weight and go right".
2-1 Pulls	"I understand" or "Talk to me".	4 Pulls	"Face the weight and go left".
3-2 Pulls	"More air".		
4-3 Pulls	"Less air".		
Special Signals From the Diver		**Emergency Signals From the Diver**	
1-2-3 Pulls	"Send me a square mark".	2-2-2 Pulls	"I am fouled and need the assistance of another diver".
5 Pulls	"Send me a line".	3-3-3 Pulls	"I am fouled but can clear myself".
2-1-2 Pulls	"Send me a slate".	4-4-4 Pulls	"Haul me up immediately"
		ALL EMERGENCY SIGNALS WILL BE ANSWERED AS GIVEN EXCEPT 4-4-4	

returned by the diver, the surface signal is sent again. A continued absence of confirmation is assumed to mean one of three things: the line has become fouled, there is too much slack in the line, or the diver is in trouble.

If communications are lost, the Diving Supervisor must be notified immediately and steps taken to identify the problem. The situation is treated as an emergency (refer to Paragraph 4-10.5.5).

There are three line-pull signals which are not answered immediately. Two of these, from diver to tender, are "Haul me up" and "Haul me up immediately". Acknowledgement consists of initiation of the action. The other signal, from the tender to diver, is "Come up." This signal is not acknowledged until the diver is ready to leave the bottom. If for some reason the diver cannot respond to the order, the diver must communicate the reason via the voice intercom system or through the line-pull signal meaning "I understand", followed (if necessary) by an appropriate emergency signal.

A special group of searching signals is used by the tender to direct a diver in moving along the bottom. These signals are duplicates of standard line-pull signals, but their use is indicated by an initial seven-pull signal to the diver which instructs the diver to interpret succeeding signals as searching signals. When the tender wants to revert to standard signals, another seven-pull signal is sent to the diver which means searching signals are no longer in use. Only the tender uses searching signals; all signals initiated by the diver are standard signals. To be properly oriented for the use of searching signals, the diver must be in a position facing the line (either the lifeline or the descent line, if a circling line is being employed).

6-9 DIVING TECHNIQUES AND PROCEDURES

6-9.1 Preparing to Dive. The predive activities for a surface-supplied diving operation will involve many people and include the inspection and assembling of equipment, activation of air supply systems, and dressing of divers.

A comprehensive predive checklist is developed to suit the requirements of the diving unit and of the particular operation. This is in addition to the general Planning Checklist and the Safety Checklist, both of which are discussed in Chapter 4. A suggested Predive Checklist is presented in Chapter 4.

The diving station is neatly organized with all diving and support equipment placed in an assigned location. Deck space must not be cluttered with gear; items which could be damaged are placed out of the way (preferably off the deck). A standard layout pattern should be established and followed.

The primary and secondary air supply systems are checked to ensure that competent personnel are on station to operate and stand watch over the systems. Air compressors of the divers' air system are started and checked for proper operation. The pressure in the accumulator tanks is checked. If HP air cylinders are being used, the manifold pressure is checked. A sufficient quantity of air must be on hand for the operation. If a compressor is being used as a secondary air supply, it is started and kept running throughout the dive. The air supply must meet purity standards (Paragraph 6-7.1.1).

Depth soundings are taken and descent line, stage, stage lines, and connections are checked, with decompression stops properly marked.

If available, the recompression chamber is inspected, and all necessary equipment and a copy of appropriate recompression treatment tables are placed on hand and in the chamber. Two stop watches and the decompression tables are also required. Adequate air supply for immediate pressurization of the chamber is verified, and the oxygen supply system is charged and made ready for operation in accordance with Appendix D.

When the Diving Supervisor is satisfied that all equipment is on station and in good operating condition, the next step is to dress the divers. This is the responsibility of the tender. When using MK 12 SSDS, more than one tender will be needed to assist with dressing the diver.

6-9.2 Diving Supervisor Predive Checklist. The Diving Supervisor must always use a predive checklist prior to putting divers in the water. This checklist must be tailored by the unit to the specific equipment and systems being used. Figure 4-20, pages 4-43 through 4-47, contains typical predive checklists for surface-supplied equipment. Refer to the appropriate operations and maintenance manual for detailed checklists for specific equipment.

6-9.3 Entering the Water. When entering the water by ladder, the diver must be assisted by the tenders. The diver's movements must be slow and cautious, especially when nearing the water, to guard against being pushed or lifted off the ladder by wave action.

If entering by stage, the diver centers himself on the platform or seat and takes a good grip on the bails. When standing, the diver's feet are apart with the legs slightly bent to absorb any shock if the stage drops or jerks. Upon signal from the Diving Supervisor, the winch operator and line handlers take a strain on the stage line; then, following appropriate signals, they lift, guide, and lower the stage to the water, using the stage line and steadying lines.

If a diver in the lightweight outfit jumps into the water, the diver maintains a grip on the faceplate while the tender ensures sufficient slack in the umbilical.

After entering the water, the diver immediately checks for leaks in the suit or air connections. If two divers are being employed, both divers perform as many checks as possible on their own rigs and then check their dive partner's rig. The tender or another diver can be of assistance by looking for any telltale bubbles. A communications check is made and malfunctions or deficiencies not previously noted are reported now. When satisfied that the divers are ready in all respects to begin the dive, they notify the Diving Supervisor and the tenders move the divers to the descent line.

When in position for descent, the diver adjusts for negative buoyancy and signals readiness to the Diving Supervisor. If a surface swim with a MK 12 SSDS is made, the system is ventilated prior to descent.

6-9.4 Descent. Descent may be accomplished with the aid of a descent line or stage. Topside personnel must ensure that air is being supplied to the diver in sufficient quantity and at a pressure sufficient to offset the effect of the steadily increasing water pressure. The air pressure must also include an overbottom pressure allowance to protect the diver against a serious squeeze if he falls.

While descending, the diver adjusts the air supply so that breathing is easy and comfortable. The diver continues to equalize the pressure in the ears as necessary during descent, and must be on guard for any pain in the ears or sinuses, or any other warning signals of possible danger. If any such indications are noted, the descent is halted. The difficulty may be resolved by ascending a few feet to regain a pressure balance; if this is not effective, the diver is returned to the surface.

Some specific instructions for descent are as follows:

(1) With a descent line, the diver locks the legs around the line and holds on to the line with one hand.

(2) In a current or tideway, the diver descends with back to the flow in order to be held against the line and not be pulled away. If the current measures more than 1.5 knots, the diver wears additional weights or descends on a weighted stage, so that descent is as nearly vertical as possible.

(3) When the stage is used for descent, it is lowered with the aid of a winch and guided to the site by a shackle around the descent line. The diver stands in the center of the stage, maintaining balance by holding on to the side bails. Upon reaching the bottom, the diver exits the stage as directed by the Diving Supervisor.

(4) The maximum rate of descent, by any method, should not exceed 120 feet per minute (fpm), although such factors as the diver's ability to clear the ears, currents and visibility, and the need to approach an unknown bottom with caution may render the actual rate of descent considerably less.

(5) The diver signals arrival on the bottom and quickly checks bottom conditions. Conditions which are radically different than expected are reported to the Diving Supervisor. If there is any doubt about the safety of the diver or the diver's readiness to operate under the changed conditions, the dive is aborted.

(6) A diver using a MK 12 SSDS thoroughly ventilates when reaching the bottom, at subsequent intervals as the diver feels necessary, and as directed from the surface. On dives deeper than 100 fsw, the diver may not notice the CO_2 warning symptoms because of nitrogen narcosis. It is imperative that the Diving Supervisor monitors his divers' ventilation.

6-9.5 Underwater Procedures. Upon reaching the bottom and before leaving the area of the stage or descent line, the diver adjusts buoyancy and makes certain that the air supply is adequate.

The diver adjusts the air flow to the point at which the weight of the helmet group is just lifted off the shoulders without losing the necessary negative buoyancy.

The diver becomes oriented to the bottom and the work site using such clues as the lead of the umbilical, natural features on the bottom, the direction of current, and the position of the sun. However, bottom current may differ from the surface current. The direction of current flow and position to the sun may change significantly during the period of the dive. If the diver has any trouble in orientation, the tender can guide the diver by use of the line-pull searching signals.

The diver is now ready to move to the work site and begin the assignment.

6-9.6 Underwater Techniques. The following general guidelines and considerations are heeded by the diver during the conduct of the dive.

6-9.6.1 Movement on the Bottom.
Procedures for movement on the bottom areas follow.

(1) Before leaving the descent line or stage, the diver ensures that the umbilical is not fouled.

(2) The diver loops one turn of the lifeline and air hose over an arm; this will act as

a buffer against a sudden surge or pull on the lines.

(3) The diver proceeds slowly and cautiously to increase safety and to conserve energy.

(4) If obstructions are encountered, the diver adjusts buoyancy to pass over the obstruction (not under or around). If the diver must pass around an obstruction, the diver must return by the same side, to avoid fouling lines.

(5) When using buoyancy adjustments to aid in movement, the diver avoids bouncing along the bottom; all diver movements are controlled.

(6) If the current is strong, the diver stoops or crawls to reduce body area exposed to the current. Inflation of the diver's dress is adjusted to compensate for any change in depth, even if the change is only a few feet.

(7) When moving on a rocky or coral bottom, the diver ensures lines do not become fouled on outcroppings, guarding against tripping and getting feet caught in crevices. The diver watches for sharp projections which can cut hoses, diving dress, or unprotected hands. The tender is particularly careful to take up any slack in the umbilical to avoid fouling.

(8) The diver is on guard against slipping and falling on gravel bottoms, especially on slopes.

(9) Unnecessary movements that stir up the bottom and impair visibility are avoided. If wearing MK 12 SSDS, buoyancy is increased slightly to keep out of the mud when possible.

CAUTION

Avoid overinflation and be aware of the possibility of blowup when breaking loose from mud. It is better to call for aid from the standby diver than to risk blowup.

(10) Mud and silt may not be solid enough to support the diver. Divers may spend many hours working under mud without unreasonable risk. The primary hazard with mud bottoms comes from the concealment of obstacles and dangerous debris.

6-9.6.2 Guidelines for MK 12 SSDS Normal Air Configuration. Guidelines for the MK 12 SSDS normal air configuration follow.

- To alter buoyancy in MK 12 SSDS equipment for short periods of time without disturbing the normal adjustment of the air control and exhaust valves, the chin button inside the helmet is used. By pushing the button with the chin, the exhaust valve is fully opened, resulting in rapid deflation of the dress. By pulling the button with the lips, the exhaust is momentarily shut off and rapid inflation occurs.

- Any adjustments to the air control valve are made in small, cautious increments. The maximum discharge of the exhaust valve is equal to the quantity of air that flows through an air control valve that is one-half open.

- In order to lessen the possibility of a valve sticking in the closed position, the air control valve is not completely closed, except in the event of a hose rupture or when the air hose is being replaced.

- If the air supply fails or is reduced, the nonreturn valve is fully seated automatically by the pressure differential. The exhaust valve, if open, is closed immediately by hand.

6-9.6.3 Searching on the Bottom. If appropriate electronic searching equipment is not available, it may be necessary to use unaided divers to conduct the search. Procedures for searching on the bottom with unaided divers follow.

(1) A diver search of the bottom can be accomplished with a circling line, using the descent line as the base point of the search. The first sweep is made with the circling line held taut at a point determined by the range of visibility. If possible, the descent line should be in sight or, if visibility is limited, within reach. The starting point is established by a marker, a line, orientation with the current or the light, signals from topside, or a wrist compass. After a full 360-degree sweep has been made, the diver moves out along the circling line another increment (roughly double the first) and makes a second sweep in the opposite direction to avoid twisting or fouling the lifeline and air hose.

(2) If the object is not found when the end of the circling line has been reached, the base point (the descent line) is shifted. Each base point in succession should be marked by a buoy to avoid unnecessary duplication in the search. If the search becomes widespread, many of the marker buoys can be removed, leaving only those which mark the outer limits of the area.

(3) If the diver is unable to make a full circle around the descent line because of excessive current or obstructions, the search patterns are adjusted accordingly.

(4) A linear search pattern can be established by laying two large buoys and setting a line between them. A diving launch, with a diver on the bottom, can follow along the line from buoy to buoy, coordinating progress with the diver who is searching to each side of the established base line.

(5) Once the object of a search is located, it is marked. The diver can secure the circling line to the object as an interim measure, while waiting for a float line to be sent down.

6-9.6.4 Unusual Situations. Guidelines for working with unusual situations follow:

- When working around corners where the umbilical is likely to become fouled or line-pull signals may be dissipated, a second diver (tending diver) is sent down to tend the lines of the first diver at the obstruction and to pass along any line-pull signals. Line-pull signals are used when audio communications are lost and are passed on the first diver's lines; the tending diver uses his own lines only for signals directly pertaining to his own situation.

- When working inside a wreck, the same procedure of deploying tending divers is followed. This technique applies to the tending divers as well: every diver who penetrates a deck level has another tending diver at that level, or levels, above. Ultimately, the number of tending divers deployed depends on the situation and the good judgement of the Diving Officer, Master Diver, and Diving Supervisor on the site. Obviously, an operation requiring penetration through multiple deck levels requires detailed advanced planning in order to provide for the proper support of the number of divers required. MK 12 SSDS and MK 21 MOD 1 are the only equipment approved for working inside a wreck.

- The diver enters a wreck feet first and never uses force to gain entry through an opening.

- When working with or near lines or moorings, observe the following rules:

(1) Stay away from lines under strain.

(2) Avoid passing under lines or moorings if at all possible; avoid brushing against lines or moorings which have become encrusted with barnacles.

(3) If a line or mooring is to be shifted, the diver is brought to the surface and, if not removed from the water, moved to a position well clear of any hazard.

(4) If a diver must work with several lines (messengers, float lines, lifting lines, etc.) each should be distinct in character (size or material) or marking (color codes, tags, wrapping).

(5) Never cut a line unless the line is positively identified.

(6) When preparing to lift heavy weights from the bottom, the lines selected must be strong enough and the surface platform must be positioned directly over the object to be raised. Prior to the lift, the diver leaves the water.

6-9.6.5 Bottom Checks. Bottom checks are conducted after returning to the stage or descent line and prior to ascent. The checks are basically the same for each rig.

(1) Ensure all tools are ready for ascent.

(2) Check exhaust valve (MK 12 only).

(3) Check that all umbilicals and lines are clear for ascent.

(4) Assess and report your condition (level of fatigue, remaining strength, physical aches or pains, etc.) and mental acuity.

6-9.7 Job Site Procedures. The range of diving jobs is wide and varied. Many jobs follow detailed work procedures and require specific predive training to ensure familiarity with the work. The *U.S. Navy Underwater Work Techniques Manual*, Volumes 1 and 2, NAVSEA 0994-LP-007-8010 and NAVSEA 0994-LP-007-8020, presents guidance for most commonly encountered jobs, including such assignments as clearing fouled propellers, patching collision damage, replacing underwater valves or fittings, preparing for salvage of sunken vessels, and the recovery of heavy objects from the bottom.

With the advent of more highly technical underwater work procedures, the *Underwater Ship Husbandry Manual*, S0600-AA-PRO-010, was published. Like the *Naval Ships Technical Manual (NSTM)*, the manual is published in separately bound chapters (i.e. S0600-AA-PRO-020, -030, -040, ...), each dealing with a separate area of underwater work. Chapter one of the manual (S0600-AA-PRO-010) is the Index and User Guide, which provides information on the subsequent chapters of the manual.

Underwater work requires appropriate tools and materials, such as cement, foam plastic, and patching compounds. Many of these are standard handtools (preferably corrosion-resistant) and materials; others are specially designed for underwater work. A qualified diver will become familiar with the particular considerations involved in working with these various tools and materials in an underwater environment. Hands-on training experience is the only way to get the necessary skills. Consult the appropriate operations and maintenance manuals for the use techniques of specific underwater tools. In working with tools the following basic rules always apply.

- Never use a tool that is not in good repair. If a cutting tool becomes dulled, return it to the surface for sharpening.

- Do not overburden the worksite with unnecessary tools, but have all tools which may be needed readily available.

- Tools are secured to the diving stage by lanyard, carried in a tool bag looped over the diver's arm, or lowered on the descent line using a riding shackle and a light line for lowering. Power tools are sent down ahead of the diver and returned to the surface before the diver ascends. Attach lanyards to all tools, connectors, shackles, and shackle pins.

- Using the diving stage as a worksite permits organization of tools while providing for security against loss. The stage also gives the diver leverage and stability when applying force (as to a wrench), or when working with a power tool which transmits a force back through the diver.

- Tying a hogging line to the work also gives the diver leverage while keeping him in close proximity to his task without continually having to fight a current.

6-9.7.1 Safety Procedures. Emergency procedures are covered specifically for each equipment in its appropriate operations and maintenance manual and in general in Chapter 4. However, there are a number of situations which a diver is likely to encounter in the normal range of activity which, if not promptly solved, can lead to full-scale emergencies. These situations and the appropriate action to be taken follow.

- **Loss of circling line -** First, the diver searches carefully within arm's reach. Then, if the line is not located, the diver does NOT enter into an area search, but informs the Diving Supervisor of the loss. In water less than 40 feet deep, the tender hauls in the umbilical and attempts to guide the diver toward the descent line. The diver approaches and secures the circling line, then signals "lower" to the tender, and returns to work. In water over 40 feet deep, the tender guides the diver to the descent line with search signals.

- **Fouled lines -** As soon as a diver discovers that the umbilical has become fouled, the diver must stop and examine the situation. Pulling or tugging without a plan may only serve to complicate the problem and could lead to a severed hose. The Diving Supervisor is notified if possible (the fouling may prevent transmission of line-pull signals). If the lines are fouled on an obstruction, retracing steps should free them. If the lines cannot be cleared quickly and easily, the standby diver is sent down to assist. The standby diver is sent down as normal procedure, should communications be interrupted and the tender be unable to haul the diver up. The standby diver, using the first diver's umbilical (as a descent line), should be able to trace and release the lines. If it is impossible to free the first diver, the standby diver should signal for a replacement lifeline and air hose.

- **Fouled descent lines -** If the diver becomes fouled with the descent line and cannot be easily cleared, it is necessary to haul the diver and the line to the surface, or to cut the weight free of the line and attempt to pull it free from topside. If the descent line is secured to an object or if the weight is too heavy, the diver may have to cut the line before being hauled up. For this reason, a diver should not descend on a line that cannot be cut. If job conditions call for use of a steel cable or a chain as a descent line, the Diving Officer must approve such use.

- **Falling -** When working at mid-depth in the water column, the diver should keep a hand on the stage or rigging to avoid falling. The diver avoids putting an arm overhead in a dry suit: air leakage around the edges of the cuffs may change the suit buoyancy and increase the possibility of a fall in the water column.

- **Damage to helmet and diving dress -** If a leak occurs in the helmet, the diver's head is lowered and the air pressure slightly increased to prevent water leakage. A leak in the diving suit only requires remaining in an upright position; water in the suit will not directly endanger breathing.

The best safety factors are a positive, confident attitude about diving, and careful advance planning for emergencies. A diver in trouble underwater should relax, avoid panic, communicate the problem to the surface, and carefully think through the possible solutions to the situation. Topside support personnel should implement emergency job-site procedures as indicated in Chapter 4, Operations Planning. In all situations, the Diving Supervisor should ensure that common sense and good seamanship prevail to safely resolve each emergency.

6-9.8 Tending the Diver. Procedures for tending the diver follow.

(1) Before the dive, the tender carefully checks the diving dress with particular attention to the exhaust valve, nonreturn valve, air control valve, helmet locking device, intercom system, helmet seal, and harness.

(2) When the diver is ready, the tenders dress and assist the diver to the stage or ladder, always keeping a hand on the lifeline close to the helmet to prevent a fall.

(3) The primary tender and a backup tender are always on station to assist the diver. As the diver enters the water, the tenders handle the umbilical, leading it over a bulwark or deck-edge roller whenever possible, using care to avoid sharp edges. The umbilical must never be allowed to run free or be belayed around a cleat or set of bitts. Pay out of the umbilical is at a steady rate to permit the diver to descend smoothly. If a stage is being used, the descent rate is coordinated with the winch operator or line handlers.

(4) Throughout the dive the tender keeps slack out of the line while not holding it too tautly. Two or three feet of slack permits the diver freedom of movement and prevents the diver from being pulled off the bottom by surging of the support craft or the force of current acting on the line. The tender occasionally checks the umbilical to ensure that movement by the diver has not resulted in excessive slack. Excessive slack makes signaling difficult, hinders the tender from catching the diver if falling, and increases the possibility of fouling the umbilical.

(5) The tender monitors the umbilical by feel and the descent line by sight for any line-pull signals from the diver. If an intercom is not being used, or if the diver is silent, the tender periodically verifies the diver's condition by line-pull signal. If the diver does not answer, the signal is repeated; if still not answered, the Diving Supervisor is notified. If communications are lost, the situation is treated as an emergency (see Chapter 4 for loss of communication procedures).

6-9.9 Monitoring the Diver's Movements. The Diving Supervisor and designated members of the dive team constantly monitor the diver's progress and keep track of his relative position. This is done as follows:

(1) Supervisor -

(a) Follow the bubble trail. If the diver is searching the bottom, bubbles move in a regular pattern. If the diver is working in place, bubbles do not shift position. If the diver has fallen, the bubbles may move rapidly off in a straight line.

(b) Monitor the pneumofathometer pressure gauge to keep track of operating depth. If the diver remains at a constant depth or rises, the gauge provides a direct reading, without the need to add air. If the diver descends, the hose must be cleared and a new reading made.

(2) Tender - Feel the pull of the umbilical.

(3) Pneumatic tender - Feel the vibration in the air-power lines of pneumatic tools.

(4) Additional personnel as assigned - Monitor the gauges on the supply systems for any powered equipment. For example, the ammeter on an electric welding unit indicates a power drain when the arc is in use; the gas pressure gauges for a gas torch registers the flow of fuel. Additionally, the pop made by a gas torch being lighted will probably be audible over the intercom, and bubbles from the torch will break on the surface, giving off small quantities of smoke.

6-9.10 Ascent. Ascent procedures follow.

(1) To prepare for a normal ascent, the diver clears the job site of tools and equipment. These can be returned to the surface by special messenger lines sent down the descent line. If the diver cannot find the descent line and needs a special line, this can be bent onto his umbilical and pulled down by the diver. The diver must be careful not to foul the line as it is laid down. The tender then pulls up the slack. This technique is useful in shallow water, but not practical in deep dives.

(2) If possible, the diving stage is positioned on the bottom. If some malfunction such as fouling of the descent line prevents lowering the stage to the bottom, the stage should be positioned below the first decompression stop if possible. Readings from the pneuomofathometer are the primary depth measurements.

(3) If ascent is being made using the descent line or the stage has been positioned below the first decompression stop, the tender signals the diver "Standby to come up" when all tools and extra lines have been cleared away. The diver acknowledges the signal, increases buoyancy slightly to ease the weight that must be hauled up, and wraps a leg around the descent line. The diver, however, does not pull up or lighten the weight to float toward the surface. The tender lifts the diver off the bottom when the diver signals "Ready to come up," and the tender signals "Coming up. Report when you leave the bottom." The diver so reports.

(4) If, during the ascent, the diver becomes too buoyant and rises too quickly, the diver checks the ascent by clamping his legs on the descent line and adjusting the buoyancy with the exhaust valve and air control valve.

(5) The rate of ascent is a critical factor in

decompressing the diver: ascent must be carefully controlled at 30 feet per minute by the tender). The ascent is monitored with the pneumofathometer. The diver is warned by the tender when nearing the level of the stage to avoid colliding with it. As the diver reaches the stage and climbs aboard, topside is notified of arrival. The stage is then brought up to the first decompression stop.

(6) Details of decompression procedure, including explanation of the tables, are presented in Chapter 7.

(7) While ascending and during the decompression stops, the diver must be satisfied that no symptoms of physical problems have developed. If the diver feels any pain, dizziness, numbness, etc., the diver immediately notifies topside. During this often lengthy period of ascent, the diver also checks to ensure that his umbilical is not becoming fouled on the stage line, the descent line, or by any steadying weights hanging from the stage platform.

(8) Upon arrival at the surface, the diver takes a firm hold on the bails of the stage and signals readiness to the tenders. The topside personnel, timing the movement as dictated by any surface wave action, coordinate bringing the stage and umbilical up and over the side.

(9) If the diver exits the water via the ladder, the tenders provide assistance. The diver will be tired and a fall back into the water could result in serious injury. Under no conditions is any of the diver's gear to be removed before the diver is firmly on deck.

6-9.11 Surface Decompression.
Decompression in the water column is time consuming, uncomfortable, and inhibits the ability of the support vessel to get underway. Delay could also present other problems for the support vessel: weather, threatened enemy action, or operating schedule constraints. In-water decompression delays medical treatment, when needed, and increases the possibility of severe chilling and accident. For these reasons, decompression is often acomplished in a recompression chamber on the support ship. Refer to Chapter 7 for surface decompression procedures.

When transferring a diver from the water to the chamber, the tenders are allowed no more than three and one half minutes to undress the diver. In this time they remove all diver's gear except UDT shorts. A tender or diving medical personnel, as required by the nature of the dive or the condition of the diver, must be in the chamber with any necessary supplies prior to arrival of the diver. The time factor is critical and delays cannot be tolerated. Undressing a diver for surface decompression should be practiced until a smooth, coordinated procedure is developed.

6-9.12 Postdive Procedures. Postdive procedures are planned in advance to ensure personnel are carefully examined for any possible injury or adverse effects, and equipment is inspected, maintained, and stowed in good order.

- Personnel and Reporting. Immediate postdive activities include any required medical treatment for the diver and the recording of mandatory reports.

(1) Medical treatment is administered for cuts or abrasions. The general condition of the diver is monitored until problems are unlikely to develop. The Diving Supervisor resets the stopwatch after the diver reaches the surface and remains alert for irregularities in the diver's actions or mental state. The diver must remain within 30 minutes travel time of

the diving unit for at least two hours after surfacing.

(2) Divers should not fly for 12 hours after surfacing from a decompression dive or for 2 hours following a no-decompression dive. If aircraft cabin pressure is below 2,300 feet altitude, then flying may be done immediately after any air dive.

(3) Mandatory records and reports are covered in Chapter 4 and Appendix E. Certain information is logged as soon as the diving operations are completed, while other record keeping is scheduled when convenient. The recorder is responsible for the diving log, which is kept as a running account of the dive. The diver is responsible for making appropriate entries in the personal diving record. Other personnel, as assigned, are responsible for maintaining equipment usage logs.

- Equipment. A postdive checklist, tailored to the equipment used, is followed to ensure equipment receives proper maintenance prior to storage. Postdive maintenance procedures are contained in the equipment operation and maintenance manual and the planned maintenance system package.

CHAPTER SEVEN

AIR DECOMPRESSION

7-1 INTRODUCTION

As discussed in Chapter 3, when air is breathed under pressure, nitrogen diffuses into various tissues of the body. This nitrogen uptake by the body occurs at different rates for the various tissues. It continues as long as the partial pressure of the inspired nitrogen in the circulatory and respiratory systems is higher than the partial pressure of the gas absorbed in the tissues. Hence, the amount of nitrogen absorbed is depth and time dependent. Nitrogen absorption increases as the partial pressure of the inspired nitrogen increases, i.e., with increased depth. Nitrogen absorption also increases as the duration of the exposure increases, i.e., with increased bottom time.

As a diver begins to ascend, the process is reversed as the partial pressure of nitrogen in the tissues exceeds that in the circulatory and respiratory systems. The pressure gradient from the tissues to the blood and lungs must be carefully controlled to prevent too rapid a diffusion of nitrogen. If the pressure gradient is uncontrolled, bubbles of nitrogen gas can form in tissues and blood causing decompression sickness.

To reduce the possibility of decompression sickness, special decompression tables and schedules were developed. These tables take into consideration the amount of nitrogen absorbed by the body at various depths and times. Other considerations are the allowable pressure gradients which can exist without excessive bubble formation and the different gas elimination rates associated with various body tissues.

Because of its operational simplicity, staged decompression is used for air decompression. This decompression requires decompression stops in the water at various depths for specific periods of time.

Years of scientific study, calculations, animal and human experimentation, and extensive field experience all contributed to the decompression tables. While the tables contain the best information available, as dive depth and time increase, the tables tend to be less accurate and require very careful application. To ensure maximum diver safety, the tables must be strictly followed. Deviations from established decompression procedures are not permitted except in an emergency and with the guidance and recommendations of a Diving Medical Officer (DMO).

This chapter discusses five different tables, each with its own unique application in air diving. Four tables provide specific decompression data for use under various operational conditions. The fifth is used when determining decompression requirements when a diver will dive more than once during a 12-hour period.

7-2 DEFINITION OF TERMS

The following are terms frequently used when conducting diving operations and in discussions of the decompression tables.

- **DESCENT TIME** - The total elapsed time from when the divers leave the surface to the time (rounded up to the next whole minute) when they reach the bottom.

- **BOTTOM TIME** - The total elapsed time from when the divers leave the surface to the time (rounded up to the next whole minute) they begin their ascent from the bottom or from the deepest depth attained. This time is measured in minutes.

- **DECOMPRESSION TABLE** - A structured set of decompression schedules, or limits, usually organized in order of increasing bottom times and depths.

- **DECOMPRESSION SCHEDULE** - A specific decompression procedure for a given combination of depth and bottom time as listed in a decompression table. It is normally indicated as feet/minutes.

- **DECOMPRESSION STOP** - A specified depth at which a diver must remain for a specified length of time (stop time). The purpose is to eliminate inert gases from the body.

- **DEPTH** - When used to indicate the depth of a dive, the following terms are used:

(1) **Deepest Depth:** The deepest pneumofathometer reading obtained when conducting surface-supplied diving.

(2) **Maximum Depth:** The deepest depth corrected for pneumofathometer error according to Table 7-1. When conducting SCUBA operations, the deepest depth gauge reading.

(3) **Stage Depth:** The pneumofathometer reading taken when the divers are on the stage just prior to leaving the bottom. Stage depth is used to compute the distance and travel time to the first stop or to the surface if no stops are required.

Table 7-1. Pneumofathometer Correction Factors.

Pneumofathometer Depth	Correction Factor
0-100 fsw	+ 1 fsw
101-200 fsw	+ 2 fsw
201-300 fsw	+ 4 fsw
301-400 fsw	+ 7 fsw

Example: On the bottom, the diver's deepest pneumofathometer reading is 250 fsw. What is the diver's maximum depth?

Solution: In the depth range of 201-300 fsw, the pneumofathometer underestimates the diver's depth by 4 fsw. To determine the maximum depth, 4 fsw must be added to the pneumofathometer reading. The diver's maximum depth is 254 fsw.

- **EQUIVALENT SINGLE DIVE BOTTOM TIME** - The time, in minutes, for which the schedule of a single repetitive dive is selected.

- **NO DECOMPRESSION (No "D") Limits** - The maximum time which can be spent at a given depth such that safe ascent can be made directly to the surface at a prescribed rate with no decompression stops.

- **REPETITIVE DIVE** - Any dive conducted within 12 hours of a previous dive.

- **REPETITIVE GROUP DESIGNATION** - A letter which is used to relate directly to the amount of residual nitrogen remaining in a diver's body.

- **RESIDUAL NITROGEN -** Nitrogen gas that is still dissolved in a diver's tissues after surfacing.

- **RESIDUAL NITROGEN TIME -** Time, in minutes, which must be added to the bottom time of a repetitive dive to compensate for the nitrogen still in solution in a diver's tissues from a previous dive.

- **SINGLE DIVE -** Any dive conducted more than 12 hours after a previous dive.

- **SINGLE REPETITIVE DIVE -** A dive for which the bottom time used to select the decompression schedule is the sum of the residual nitrogen time and the actual bottom time of the dive.

- **SURFACE INTERVAL -** The time which a diver has spent on the surface following a dive. It begins as soon as the diver surfaces and ends as soon as he starts his next descent.

7-3 TABLE SELECTION

The following decompression tables are available for U.S. Navy diving operations:

- No-Decompression Limits and Repetitive Group Designation Table

- Standard Air Decompression Table

- Surface Decompression Table Using Oxygen

- Surface Decompression Table Using Air

- Residual Nitrogen Timetables for repetitive air diving

These tables present a series of decompression schedules which must be rigidly followed during an ascent from an air dive. Each table has specific conditions which justify its selection. These conditions are: depth and duration of the dive, availability of an oxygen breathing system within the recompression chamber, and environmental conditions (sea state, water temperature, etc.).

The Residual Nitrogen Timetable for Repetitive Air Dives provides information for planning repetitive dives.

The five air diving tables and the criteria for the selection and application of each are listed in Table 7-2. General instructions for using the tables and special instructions applicable to each table are discussed in Paragraphs 7-4 and 7-5, respectively.

NOTE

Omitted decompression is a dangerous situation that must be made up for. Procedures for dealing with this situation are discussed in Chapter 8, Section C.

7-3.1 Dive Recording. Appendix E provides information for maintaining a Command Diving Log, personal diving log, and for reporting individual dives to the Naval Safety Center. In addition to these records, every Navy air dive may be recorded on a diving chart similar to Figure 7-1. The diving chart is a convenient means of collecting the dive data, which in turn will be transcribed in the dive log. Following is a list of Diving Record abbreviations which may be used in the Command Diving Log:

LS - Left Surface

RB - Reached Bottom

LB - Left Bottom

R - Reached a stop

L - Left a stop

DIVING CHART - AIR

	Date

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)

TENDERS (DIVER 1) AND	TENDERS (DIVER 2) AND

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
LEFT BOTTOM (LB)	TOTAL BOTTOM TIME (TBT)	TABLE & SCHEDULE USED	TIME TO FIRST STOP
REACHED SURFACE (RS)	TOTAL DECOMPRESSION TIME (TDT)	TOTAL TIME OF DIVE (TTD)	REPETITIVE GROUP

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME		TIME	
			WATER	CHAMBER	WATER	CHAMBER
		10			L R	
		20			L R	
		30			L R	
		40			L R	
		50			L R	
		60			L R	
		70			L R	
		80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
		130			L R	

PURPOSE OF DIVE	REMARKS
DIVER'S CONDITION	DIVING SUPERVISOR

Figure 7-1. Diving Chart - Air.

Table 7-2. Air Decompression Tables Selection Criteria.

Table	Application
U.S. Navy Standard Air Decompression Table	No locally available recompression chamber. Conditions dictate in-water decompression permissible. Normal and exceptional exposure dive schedules. Repetitive dives; normal decompression schedules only.
No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Air Dives	Decompression not required. Repetitive dives.
Residual Nitrogen Timetable for Repetitive Air Dives	Repetitive Group designations after surface intervals greater than 10 minutes and less than 12 hours. Residual nitrogen times for repetitive air dives.
Surface Decompression Table Using Oxygen	Available recompression chamber with oxygen breathing system. Conditions dictate in-water decompression undesireable. Repetitive dives combine to single dive.
Surface Decompression Table Using Air	Available recompression chamber without an oxygen breathing system; or diver forced to surface prior to completing decompression. Conditions dictate in-water decompression undesireable. Repetitive dives combine to single dive.

RS - Reached Surface

TBT - Total Bottom Time (Computed from leaving the surface to leaving the bottom)

TDT - Total Decompression Time (computed from leaving the bottom to reaching the surface)

TTD - Total Time of Dive (Computed from leaving the surface to reaching the surface).

Figure 7-2 illustrates these abbreviations in conjunction with a dive profile.

7-3.2 No-Decompression Limits and Repetitive Group Designation Table For No-Decompression Air Dives. The No-Decompression Table serves two purposes. First, it summarizes all the depth and bottom time combinations for which no decompression is required. Second, it provides the repetitive group designation for each no-decompression dive. Even though decompression is not required, there is still an amount of nitrogen remaining in the diver's tissues for up to 12 hours following a dive. If they dive again within a 12-hour period, divers must consider this residual nitrogen when calculating decompression from the repetitive dive.

Each depth listed in the No-Decompression Table has a corresponding no-decompression limit listed in minutes. This limit is the maximum bottom time that divers may spend at that depth without requiring decompression. Use the columns to the right of the no-decompression limits column to obtain the repetitive group designation. This designation must be assigned to a diver subsequent to every dive.

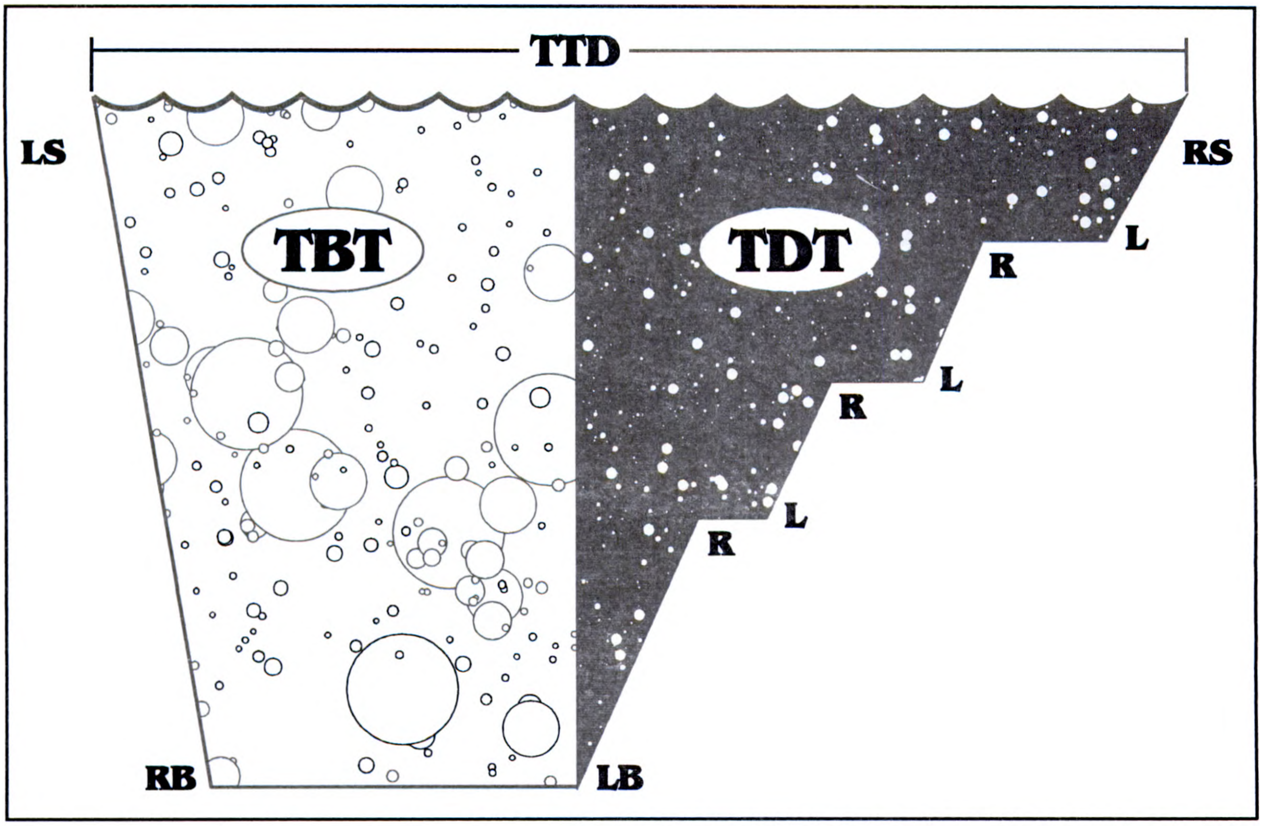


Figure 7-2. Graphic View of a Dive with Abbreviations.

To find the repetitive group designation, enter the table at the depth equal to, or next greater than, the maximum depth of the dive. Follow that row to the right to the bottom time equal to, or just greater than, the actual bottom time of the dive. Follow the column up to the repetitive group designation.

Any dive deeper than 35 fsw which has a bottom time greater than the no-decompression limit given in this table is a decompression dive and must be conducted per the Standard Air Decompression Table.

Example: In planning a dive, the Dive Supervisor desires the divers to conduct a brief inspection of the work site, located at a depth of 157 fsw. Determine the maximum no-decompression limit and repetitive group designation.

Solution: The maximum bottom time which may be used without requiring decompression, and the repetitive group designation after the dive, are found in the No-Decompression Table. The no-decompression limit corresponding to the 160-fsw depth in the No-Decompression Table (which is found in the No-Decompression Limits (min) column) is five minutes. To avoid having to make decompression stops, the divers must descend to 157 fsw, make the inspection and begin ascent within five minutes of leaving the surface. Follow the 160-fsw entry to the right to the 5-minute bottom time entry and then follow it vertically to the top of the column. This shows the repetitive group designation to be D.

This same information is found in the Standard Air Decompression Table. Enter the table at the 160-fsw entry and follow the five minute bottom time row all the way horizontally to the right. There is a "0" listed in the decompression stops column and D is depicted in the Repetitive Group column.

Figure 7-3 is a diving chart for this dive.

7-3.3 Selection of Decompression Schedule. The decompression schedules of all the tables are given in 10-foot depth increments and, usually, 10-minute bottom time increments. Depth and bottom time combinations from dives, however, rarely match the decompression schedules exactly. **To ensure that the selected decompression schedule is always conservative, always select the schedule depth equal to or next greater than the maximum depth of the dive.**

As previously mentioned, a pneumofathometer is used to determine depth when conducting surface-supplied diving operations. When using an air-filled pneumofathometer to measure depth, the observed depth reading must be corrected as shown in Table 7-1. The pneumofathometer must be at mid-chest level on the diver. **Always select the schedule bottom time equal to or next longer than the bottom time of the dive.**

For example, to use the Standard Air Decompression Table to select the correct schedule for a dive to 97 fsw for 31 minutes, decompression would be selected for 100 fsw and carried out per the 100 fsw for 40 minutes (100/40) schedule.

CAUTION

Never attempt to interpolate between decompression schedules.

If the divers are exceptionally cold during the dive or if the work load is relatively strenuous, select the next longer decompression schedule than the one that would normally be selected.

NOTE

Take into consideration the physical condition of the diver when determining what is strenuous.

For example, the normal schedule for a dive to 90 fsw for 34 minutes would be the 90/40 schedule. If the divers are exceptionally cold or fatigued, they should decompress according to the 90/50 schedule. As can be seen by looking at the 90-foot schedule, the difference in decompression between the 40 and 50 minute bottom times is eleven minutes. Use this procedure because while the divers are at depth working, they are generating heat and on-gassing at a normal rate. Once decompression starts, however, the divers are at rest and begin to chill. Vasoconstriction of the veins takes place and they do not off-gas at the normal rate. The additional decompression time increases the likelihood that the divers will receive adequate decompression.

7-4 GENERAL USE OF DECOMPRESSION TABLES

7-4.1 Rules During Ascent. After selecting the applicable decompression schedule, it is imperative that it be followed as closely as possible. Unless a Diving Medical Officer recommends a deviation and the Commanding Officer concurs, decompression must be completed according to the schedule selected.

Always ascend at a rate of 30 fpm (::20 per 10 fsw). Minor variations in the rate of travel between 20 and 40 fsw/minute are acceptable. Any variation in the rate of ascent must be corrected in accordance with the procedures in paragraph 7-4.2. However, a delay of up to one minute in reaching the first decompression stop can be ignored. During decompression stops the

0811

DIVING CHART - AIR

Date 10 DEC 92

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
HARDY B.	MK-21 MOD 1	WET SUIT	2250
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
HENDERSON P.	MK-21 MOD 1	WET SUIT	2250

TENDERS (DIVER 1)	TENDERS (DIVER 2)
RUTH AND GASSETT	LECHNER AND LAWRIN

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
0800	165 + 2 = 157	~~0803~~	:03
LEFT BOTTOM (LB)	TOTAL ~~BOTTOM~~ TIME (TBT)	TABLE & SCHEDULE USED	TIME TO FIRST STOP
0805	:05	160 / 05 NO "D"	:05::10
REACHED SURFACE (RS)	TOTAL DECOMPRESSION TIME (TDT)	TOTAL TIME OF DIVE (TTD)	REPETITIVE GROUP
0810::10	:05::10	10::10	D

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:05::10	10			L R	
		20			L R	
		30			L R	
		40			L R	
		50			L R	
75	30	60			L R	
FP	FP	70			L R	
M	M	80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
:03		155 ~~130~~			L 0805 R ~~0803~~	

PURPOSE OF DIVE	REMARKS
INSPECTION DIVE SITE	OK TO REPET
DIVER'S CONDITION	DIVING SUPERVISOR
OK RED OK YELLOW	ENCM (MDV) GRAY

Figure 7-3.

diver's mouth should be located as closely as possible to the stop depth.

Decompression stop times, as specified in the decompression schedule, begin as soon as the divers reach the stop depth. Upon completion of the specified stop time, the divers ascend to the next stop or to the surface at the proper ascent rate. Ascent time is not included as part of stop time.

7-4.2 Variations in Rate of Ascent. The following rules for correcting variations in rate of ascent apply to Standard Air Decompression dives as well as Surface Decompression Table dives. For ease of illustration, the following examples address Standard Air dives.

- On a Standard Air Dive, if a rate of ascent of less than 30 fpm causes a delay of more than one minute in reaching the first decompression stop, and this delay occurs deeper than 50 fsw, add the total delay time (rounded up to the next whole minute) to the bottom time, recompute a new decompression schedule, and decompress accordingly.

  Example: A dive was made to 118 fsw with a bottom time of 60 minutes. According to the 120/60 decompression schedule of the Standard Air Decompression Table, the first decompression stop is 30 feet. During ascent, the divers were delayed at 100 fsw for :03::27 and it actually took 4 minutes 53 seconds to reach the 30-foot decompression stop.

  Solution: If the divers had maintained an ascent rate of 30 fpm, it would have taken the divers 2 minutes 52 seconds to ascend from 116 fsw to 30 fsw. The difference between what it should have taken and what it actually took is 3 minutes 27 seconds. Increase the bottom time from 60 minutes to 64 minutes (3 minutes 27 seconds rounded up), recompute the decompression schedule using a 70-minute bottom time and continue decompression according to the new decompression schedule, 120/70. This dive is illustrated in Figure 7-4.

- On a Standard Air Dive, if the rate of ascent is less than 30 fpm and the delay occurs shallower than 50 fsw, add the delay time to the diver's first decompression stop.

  Example: A dive was made to 118 feet with a bottom time of 60 minutes. According to the Standard Air Decompression Table, the first decompression stop is at 30 fsw. During ascent, the divers were delayed at 40 feet and it actually took five minutes to reach the 30-foot stop.

  Solution: As in the preceding example, the correct ascent time should have been 2 minutes 52 seconds. Because it took six minutes 26 seconds to reach the 30-foot stop, there was a delay of 3 minutes 34 seconds (six minutes 26 seconds minus 2 minutes 52 seconds). Therefore, increase the length of the 30-foot decompression stop by 3 minutes 34 seconds. Instead of two minutes, the divers must spend 5 minutes 34 seconds at 30 feet. This dive is illustrated in Figure 7-5.

- On a Standard Air Dive, if the rate of ascent is greater than 30 fpm, STOP THE ASCENT, allow the watches to catch up, and then continue ascent.

During SCUBA dives, divers may sometimes not concentrate on their watches during ascent. A good "rule-of-thumb" is to watch the exhaled bubbles. If a diver is not ascending faster than his exhaled bubbles, he probably will not exceed his ascent rate.

1537

DIVING CHART - AIR

Date 10 DEC 92

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
TRUKKEN S.	MK21 MOD1	WET SUIT	2250
NAME OF DIVER 2	**DIVING APPARATUS**	**TYPE DRESS**	**EGS (PSIG)**
RUTH J.	MK 21 MOD 1	WET SUIT	2250

TENDERS (DIVER 1)	TENDERS (DIVER 2)
MURRAY AND BECK	DIETRICH AND KILPATRICK

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
1302	116 + 2 = 118	~~1304~~	:02
LEFT BOTTOM (LB)	**TOTAL BOTTOM TIME (TBT)**	**TABLE & SCHEDULE USED**	**TIME TO FIRST STOP**
1402	:06 + :04 = :64	120/: ~~60~~ :70 STD AIR	:02::52
REACHED SURFACE (RS)	**TOTAL DECOMPRESSION TIME (TDT)**	**TOTAL TIME OF DIVE (TTD)**	**REPETITIVE GROUP**
1539::19	01:34::19	02:34::19	O

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:20	10	:66 ~~:45~~		L 1635::59 R 1440::59	
	:20	20	:23 ~~:22~~		L 1440::39 R 1417::39	
	:20	30	:09 ~~:02~~		L 1417::19 R 1408::19	
	:20	40			L R	
7	3	50			L R	
5	0	60			L R	
F P	F P	70			L R	
M	M	80			L R	
		90			L R	
		100	FOULED 03::27		L 1405::59 R 1402::32	
	:32	110			L R	
		120			L R	
:02		116 ~~120~~			L 1402 R ~~1304~~	

PURPOSE OF DIVE	REMARKS
TRAINING	DIVERS FOULED AT 100 FSW FOR 03::37 ADD TO BOTTOM TIME#
DIVER'S CONDITION	**DIVING SUPERVISOR**
OK RED OK YELLOW	ENCM(MDV) ROBERTS

Figure 7-4.

DIVING CHART - AIR

1720

Date 10 DEC 92

NAME OF DIVER 1 HONEY	DIVING APPARATUS MK-12	TYPE DRESS DRY SUIT	EGS (PSIG)
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)

TENDERS (DIVER 1) BUSKI AND SLOPER T.		TENDERS (DIVER 2) AND	
LEFT SURFACE (LS) 1500	DEPTH (fsw) 116 + 02 = 118	REACHED BOTTOM (RB) ~~1502~~	DESCENT TIME :02
LEFT BOTTOM (LB) 1600	TOTAL BOTTOM TIME (TBT) :60	TABLE & SCHEDULE USED 120/60 STD "ASC"	TIME TO FIRST STOP :02::52
REACHED SURFACE (RS) 1720::00	TOTAL DECOMPRESSION TIME (TDT) 01:20::00	TOTAL TIME OF DIVE (TTD) 02:20::00	REPETITIVE GROUP O

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::20	10	:45		L 1719::40 R 1634::40	
	::20	20	:22		L 1634::20 R 1612::20	
	::20	30	05::34 ~~:02~~		L 1612::00 R 1606::26	
	::20	40	FOULED 03::34		L 1606::06 R 1602::32	
	2::32	50			L R	
75 FPM	30 FPM	60			L R	
		70			L R	
		80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
:02		116 ~~120~~			L 1600 R ~~1502~~	

PURPOSE OF DIVE REQUAL	REMARKS DELAY LESS THAN 50 FSW FOR 03::34 ADD 03::34 TO FIRST STOP. OK REPET
DIVER'S CONDITION OK RED	DIVING SUPERVISOR BMCS (MDV) BETTWA

Figure 7-5.

7-5 AIR DECOMPRESSION TABLES

7-5.1 U.S. Navy Standard Air Decompression Table (Table 7-5). This manual combines the Standard Air Decompression Table and Exceptional Exposure Air Table into one table as titled above. To clearly distinguish between the standard and exceptional exposure decompression schedules, the exceptional exposure tables have been printed in red.

NOTE

The Commanding Officer must have CNO approval to conduct planned exceptional exposure dives.

If the bottom time of a dive is less than the first bottom time listed for its depth, decompression is not required. The divers may ascend directly to the surface at a rate of 30 feet per minute (fpm). The repetitive group designation for a no-decompression dive is given in the No-Decompression Table. As noted in the Standard Air Decompression Table, there are no repetitive group designations for exceptional exposure dives. **Repetitive dives are not permitted following an exceptional exposure dive.**

Example: Divers complete a salvage dive to a depth of 145 fsw for 37 minutes. They were not unusually cold or fatigued during the dive. Determine the decompression schedule and the repetitive group designation at the end of the decompression.

Solution: Select the equal or next deeper depth and the equal or next longer bottom time. This would be the 150/40 schedule, repetitive group designator N (Figure 7-6).

7-5.2 Repetitive Dives. During the 12-hour period after an air dive, the quantity of residual nitrogen in divers' bodies will gradually be reduced to its normal level. If the divers are to make a second dive within this period (repetitive dive), they must consider their residual nitrogen level when planning for the dive.

The procedures for conducting a repetitive dive are summarized in Figure 7-7. Upon completing the first dive, the divers will have a repetitive group designation assigned to them from either the Standard Air Decompression Table or the No-Decompression Table. This designation relates directly to the residual nitrogen level upon surfacing. As nitrogen passes out of the diver's tissues and blood, their repetitive group designation changes. By using the Residual Nitrogen Timetable, this designation may be determined at any time during the surface interval.

Determine the residual nitrogen level just prior to beginning the repetitive dive. Add this time to the actual bottom time of the repetitive dive to give the bottom time of the Equivalent Single Dive. Decompression from the repetitive dive is conducted using the depth and bottom time of the equivalent single dive to select the appropriate decompression schedule. **Avoid equivalent single dives requiring the use of Exceptional Exposure decompression schedules.** Always use a systematic Repetitive Dive Worksheet, shown in Figure 7-8, when determining the decompression schedule for a repetitive dive.

If still another dive follows the repetitive dive, insert the depth and bottom time of the first equivalent single dive in Part One of the second Repetitive Dive Worksheet.

7-5.3 Residual Nitrogen Timetable for Repetitive Air Dives. The quantity of residual nitrogen in a diver's body immediately after a dive is expressed by the repetitive group designation assigned from either the Standard Air Decompression Schedule or the No-Decompression Table. The upper portion of the Residual Nitrogen Timetable is composed of various intervals between 10 minutes and 12 hours. These are expressed in hours and minutes (2:21 = 2 hours, 21 minutes). Each interval has two limits: a

1039

DIVING CHART - AIR

Date 11 DEC 92

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
LT. HARRISON	MK - 12	DRY SUIT	
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
BROOKS B.	MK - 12	DRY SUIT	

TENDERS (DIVER 1)	TENDERS (DIVER 2)
MCCUE AND FINNELLIG	FENWICK AND WILLIAMS D.

LEFT SURFACE (LS) 0900	DEPTH (fsw) 143 + 2 = 145	REACHED BOTTOM (RB) ~~0902~~	DESCENT TIME :02
LEFT BOTTOM (LB) 0937	TOTAL BOTTOM TIME (TBT) :37	TABLE & SCHEDULE USED 150/40 STD "AIR"	TIME TO FIRST STOP :03::46
REACHED SURFACE (RS) 1038::46	TOTAL DECOMPRESSION TIME (TDT) 01:01::46	TOTAL TIME OF DIVE (TTD) 01:38:46	REPETITIVE GROUP N

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:20	10	:33		L 1038::26 / R 1006::26	
	:20	20	:19		L 1006::06 / R 0946::06	
	:20	30	:05		L 0945::46 / R 0940::46	
	3::46	40			L / R	
7	3	50			L / R	
5	0	60			L / R	
FPM	FPM	70			L / R	
		80			L / R	
		90			L / R	
		100			L / R	
		110			L / R	
		120			L / R	
:02		143 ~~130~~			L 0937 / R ~~0902~~	

PURPOSE OF DIVE	REMARKS
SALVAGE	OK TO REPET
DIVER'S CONDITION	DIVING SUPERVISOR
OK RED/OK GREEN	ENCM(MDV) R. JONES

Figure 7-6.

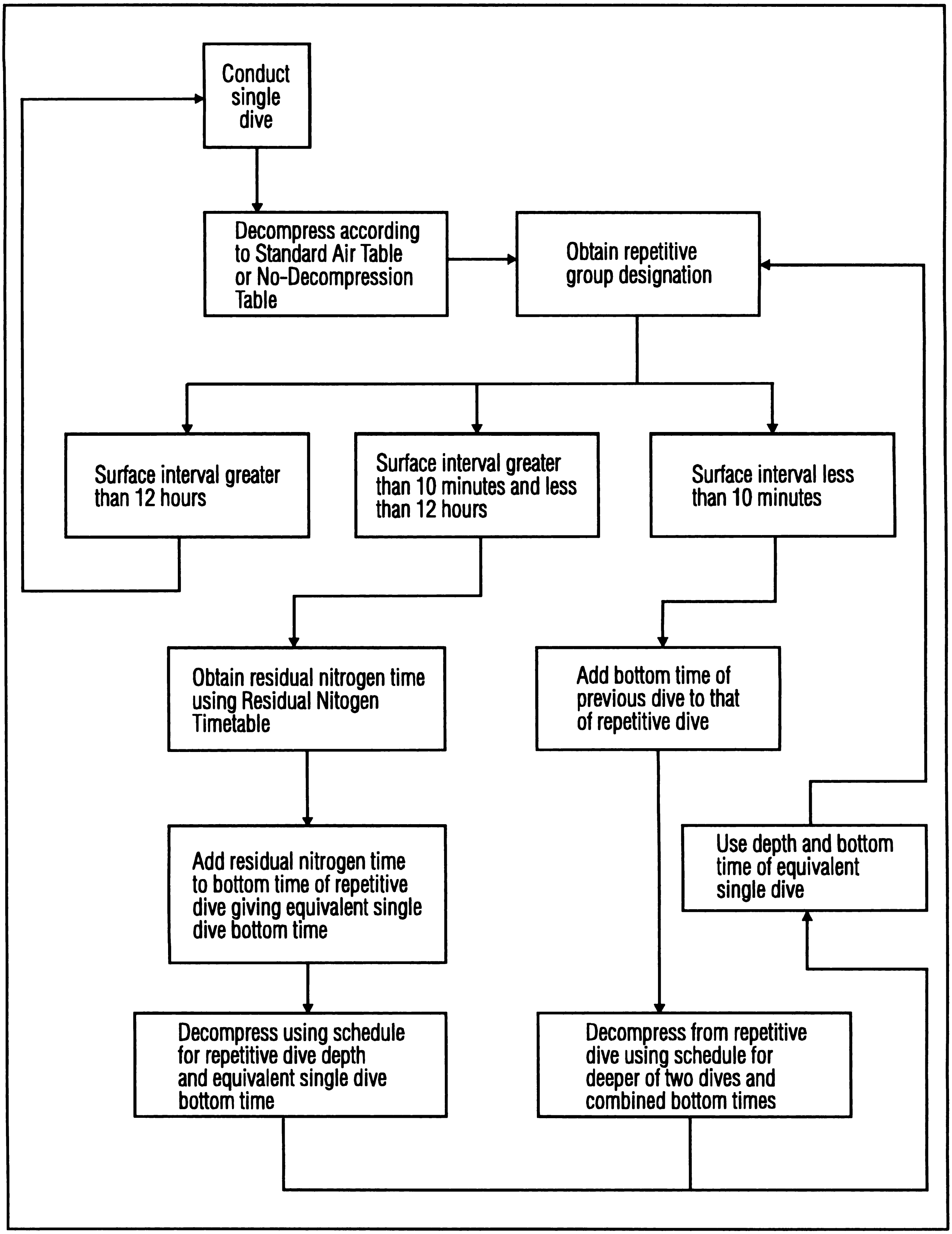


Figure 7-7. Repetitive Dive Flowchart.

REPETITIVE DIVE WORKSHEET

DATE

1. PREVIOUS DIVE:

_____ minutes ☐ Standard Air Table ☐ No-Decompression Table

___+___=___ feet ☐ Surface Table Using Oxygen ☐ Surface Table Using Air

_____ repetitive group letter designation

2. SURFACE INTERVAL:

_____ hours _____ minutes on surface

_____ repetitive group from item 1 above

_____ new repetitive group letter designation from Residual Nitrogen Timetable

3. RESIDUAL NITROGEN TIME:

___+___=___ feet, depth of repetitive dive

_____ new repetitive group letter designation from item 2 above

_____ minutes, residual nitrogen time from Residual Nitrogen Timetable or bottom time of previous Sur D dive

4: EQUIVALENT SINGLE DIVE TIME:

_____ minutes, residual nitrogen time from item 3 above or bottom time of previous Sur D dive

+ _____ minutes, actual bottom time of repetitive dive

= _____ minutes, equivalent single dive time

5. DECOMPRESSION FOR REPETITIVE DIVE:

___+___=___ feet, depth of repetitive dive

_____ minutes, equivalent single dive time from item 4 above

Decompression from (check one):

☐ Standard Air Table ☐ No-Decompression Table

☐ Surface Table Using Oxygen ☐ Surface Table Using Air

	Depth	Water	Chamber
Decompression Stops:	_____ feet	_____ minutes	_____ minutes
	_____ feet	_____ minutes	_____ minutes
	_____ feet	_____ minutes	_____ minutes
	_____ feet	_____ minutes	_____ minutes
	_____ feet	_____ minutes	_____ minutes

_______ schedule used (depth/time)

_____ repetitive group letter designation

Figure 7-8. Repetitive Dive Worksheet.

minimum time (top limit) and a maximum time (bottom limit).

Residual nitrogen times corresponding to the depth of the repetitive dive are given in the body of the lower portion of the table. To determine the residual nitrogen time for a repetitive dive, locate the diver's repetitive group designation from the previous dive along the diagonal line above the table. Read horizontally to the interval in which the diver's surface interval lies. The time spent on the surface must be between or equal to the limits of the selected interval.

Next, read vertically down to the new repetitive group designation. This corresponds to the present quantity of residual nitrogen in the diver's body. Continue down in this same column to the row which represents the depth of the repetitive dive. The time given at the intersection is the residual nitrogen time, in minutes, to be applied to the bottom time of the repetitive dive.

An exception to this table occurs when the repetitive dive is made to the same or greater depth than that of the previous dive. This is referred to as the RNT Exception Rule. In such cases, the residual nitrogen time may be longer than the bottom time of the previous dive. A diver's body cannot contain more residual nitrogen than it was originally exposed to. To obtain the equivalent single dive time, simply add the bottom time of the previous dive to that of the repetitive dive. All of the residual nitrogen passes out of a diver's body after 12 hours, so a dive conducted after a 12 hour surface interval is not a repetitive dive.

Example: A repetitive dive is planned to 98 fsw for an estimated bottom time of 15 minutes. The previous dive was to a depth of 104 fsw with a bottom time of 48 minutes. The diver's surface interval is 6 hours 26 minutes (6:26). Determine the proper decompression schedule.

Solution: Add the residual nitrogen time of the previous dive to the bottom time of the repetitive dive to obtain the equivalent single dive time. Begin in the Standard Air Decompression Table on a 110/50 schedule and read across to see that the diver's repetitive group designator is M. Moving to the Residual Nitrogen Timetable for Repetitive Air Dives, enter the table on the diagonal line at M. Read horizontally across the line until reaching the surface interval that coincides with the diver's surface interval. Since the diver's surface interval was 6 hours 26 minutes, go to the surface interval with the limits of 6:19/9:28. Now, read vertically down the table until reaching the depth that coincides with the repetitive dive depth. We arrive at the 100-foot column and find that the diver has 7 minutes of residual nitrogen to be added to the estimated bottom time of 15 minutes. Thus the diver will be decompressed on the 100/22 No Decompression schedule. Figure 7-9 depicts the dive profile for the first dive, Figure 7-10 shows the Repetitive Dive Worksheet and Figure 7-11 shows the dive profile for the repetitive dive.

7-5.4 Surface Decompression. Surface decompression is a technique for fulfilling all or a portion of a diver's decompression obligation in a recompression chamber instead of in the water. Using this technique significantly reduces the time which a diver must spend in the water. Also, breathing oxygen in the recompression chamber reduces the diver's total decompression time.

Surface decompression offers many advantages which enhance the divers' safety. Shorter exposure time in the water keeps divers from chilling

1126

DIVING CHART - AIR

Date 11 DEC 92

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
ROBERTS, DOUG	MK-21 MOD 1	WETSUIT	2250
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)

TENDERS (DIVER 1)		TENDERS (DIVER 2)	
OVERBECK AND JALBERT		AND	
LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
1000	102 + 2 = 104	~~1002~~	:02
LEFT BOTTOM (LB)	TOTAL BOTTOM TIME (TBT)	TABLE & SCHEDULE USED	TIME TO FIRST STOP
1048	:48	110/50 STD "AIR"	:02::44
REACHED SURFACE (RS)	TOTAL DECOMPRESSION TIME (TDT)	TOTAL TIME OF DIVE (TTD)	REPETITIVE GROUP
1125::24	:37::24	01:25::24	M

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:20	10	:26		L 1025::04 R 1059::04	
	:20	20	:08		L 1058::44 R 1050::44	
	2::44	30			L R	
		40			L R	
7	3	50			L R	
5 F	0 F	60			L R	
P M	P M	70			L R	
		80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
:02		102 ~~100~~			L 1048 R ~~1002~~	

PURPOSE OF DIVE	REMARKS
TRAINING	OK TO REPET
DIVER'S CONDITION	DIVING SUPERVISOR
OK RED	ENCM(MDV) ROBERTS

Figure 7-9.

REPETITIVE DIVE WORKSHEET

DATE
24 JUNE 1992

1. PREVIOUS DIVE:

:48 minutes ☒ Standard Air Table ☐ No-Decompression Table

102+02 =104 feet ☐ Surface Table Using Oxygen ☐ Surface Table Using Air

M repetitive group letter designation

2. SURFACE INTERVAL:

06 hours 26 minutes on surface

M repetitive group from item 1 above

B new repetitive group letter designation from Residual Nitrogen Timetable

3. RESIDUAL NITROGEN TIME:

97 + 01 =98 feet, depth of repetitive dive

B new repetitive group letter designation from item 2 above

:07 minutes, residual nitrogen time from Residual Nitrogen Timetable or bottom time of previous Sur D dive

4: EQUIVALENT SINGLE DIVE TIME:

:07 minutes, residual nitrogen time from item 3 above or bottom time of previous Sur D dive

\+ :15 minutes, actual bottom time of repetitive dive

= :22 minutes, equivalent single dive time

5. DECOMPRESSION FOR REPETITIVE DIVE:

97 +01 =98 feet, depth of repetitive dive

:22 minutes, equivalent single dive time from item 4 above

Decompression from (check one):

☐ Standard Air Table ☒ No-Decompression Table

☐ Surface Table Using Oxygen ☐ Surface Table Using Air

	Depth	Water	Chamber
Decompression Stops:	____ feet	____ minutes	____ minutes
	____ feet	____ minutes	____ minutes
	____ feet	____ minutes	____ minutes
	____ feet	____ minutes	____ minutes
	____ feet	____ minutes	____ minutes

100/:22 schedule used (depth/time)

G repetitive group letter designation

Figure 7-10.

1811

DIVING CHART - AIR

Date 11 DEC 92

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
HATTER	MK-21 MOD 1	WET SUIT	2250
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)

TENDERS (DIVER 1)	TENDERS (DIVER 2)
RUTTER AND DEGITZ	AND

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
1752	97 + 01 = 98	~~1754~~	:02
LEFT BOTTOM (LB)	TOTAL BOTTOM TIME (TBT) RNT	TABLE & SCHEDULE USED	TIME TO FIRST STOP
1807	15 + :07 = :22	100/22 NO "D"	:03::14
REACHED SURFACE (RS)	TOTAL DECOMPRESSION TIME (TDT)	TOTAL TIME OF DIVE (TTD)	REPETITIVE GROUP
1810::14	:03::14	18::14	G

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
		10			L / R	
		20			L / R	
		30			L / R	
		40			L / R	
75 FPM	30 FPM	50			L / R	
		60			L / R	
		70			L / R	
		80			L / R	
		90			L / R	
		100			L / R	
		110			L / R	
		120			L / R	
:02		97 ~~130~~			L 1807 / R ~~1754~~	

PURPOSE OF DIVE	REMARKS
SURVEY	OK TO REPET
DIVER'S CONDITION	DIVING SUPERVISOR
OK RED	GMCM(MDV) BROOKS

Figure 7-11.

to a dangerous level. Inside the recompression chamber, the divers can be maintained at a constant pressure, unaffected by surface conditions of the sea. Observed constantly by the inside tender and monitored intermittently by medical personnel, any signs of decompression sickness can be readily detected and immediately treated.

If an oxygen breathing system is installed in the recompression chamber, conduct surface decompression according to the Surface Decompression Table Using Oxygen. If air is the only breathing medium available, use the Surface Decompression Table Using Air. **There is no surface decompression following an exceptional exposure dive.**

Residual Nitrogen Timetables have not been developed for Surface Decompression Repetitive Dives. Repetitive dives can be made following these dives, however, as long as the bottom times of all dives made in the previous 12 hours are added, the maximum depth and time attained in the previous 12 hours are used, and the equivalent single dive does not exceed 170/40 for Sur D O_2 and 190/60 for Sur D Air.

If the allowable surface interval time is exceeded or the diver displays symptoms of decompression sickness, treat in accordance with procedures contained in Paragraphs 7-5.4.1, 7-5.4.2, and 8-13.

7-5.4.1 Surface Decompression Table Using Oxygen. Use of the Surface Decompression Table Using Oxygen (referred to as Sur D O_2) requires an approved recompression chamber with an oxygen breathing system as described in Appendix D. With Sur D O_2, there is a constant ascent rate of 30 fpm. The decision to decompress the divers using Sur D O_2 must be made prior to leaving the bottom. Once the decision is made to use Sur D O_2 and the appropriate schedule is selected, the divers are decompressed to the first decompression stop (or to the surface if there are no water stops required) at an ascent rate of 30 fpm. The travel rate between stops and from 30 fsw to the surface is also 30 fpm (::20 per 10 fsw). Minor variations in the rate of travel between 20 and 40 fpm are acceptable.

Once the divers are on the surface, the tenders have three and one-half (:03::30) minutes to remove the breathing apparatus and diving dress and assist the divers into the recompression chamber.

Pressurization of the recompression chamber with air to 40 fsw should take approximately 30 seconds (descent rate not to exceed 80 fpm). The total elapsed time from when the divers leave the 30-foot stop (or 30 fsw if no water stops are required), to when they reach the 40-foot recompression chamber stop must not exceed five minutes with the following exception: during descent in the recompression chamber, if a diver cannot clear and the chamber is to a depth of at least 20 fsw, stop at 20 fsw. Breathe oxygen at 20 fsw for twice the 40 fsw chamber stop time. Ascend to 10 fsw and breathe oxygen again for twice the 40 fsw chamber stop time. Then ascend to the surface. This "safe way out" procedure is not intended to be used in place of normal Sur D O_2 procedures if the tenders are slow in undressing the divers.

If the prescribed surface interval is exceeded and the divers are asymptomatic, treat them as if they had Type I decompression sickness (Treatment Table 5, Chapter 8). If the divers are symptomatic they are treated as if they had Type II decompression sickness (Treatment Table 6, Chapter 8), even if they are only displaying Type I symptoms. Symptoms occurring during the chamber stops are treated as recurrences (Chapter 8). Upon arrival at 40 fsw in the recompression chamber, the divers are placed on the Built-in Breathing System (BIBS) mask breathing pure oxygen. The designated 40-foot stop time commences once the divers are breathing oxygen. The divers breathe oxygen throughout the 40-foot stop and they remove the O_2 mask prior to leaving the 40 fsw stop for the surface with the following exceptions:

- Interrupt oxygen breathing after each 30 minutes with a 5-minute period of breathing chamber air (referred to as an "air break"). Count the air breaks as "dead time" and not part of the oxygen stop time. If the air break interval falls on time to travel, remain on oxygen and commence traveling. This procedure will simplify timekeeping and should be used whenever using the Surface Decompression Table Using Oxygen.

Example: A dive is planned to approximately 160 fsw for 40 minutes. The dive is to be conducted using Sur D O_2 procedures. Figure 7-12 shows this dive profile.

It is important to be aware of the appropriate schedule from the Standard Air Decompression Table and the appropriate schedule from the Surface Decompression Table Using Air. In the event the oxygen system fails while the divers are in the water, the divers are shifted to the Standard Air Decompression Table or the Surface Decompression Table Using Air. During the chamber phase, use the procedures listed below in the event of oxygen system failure or CNS oxygen toxicity.

- **Oxygen System Failure (40-fsw Chamber Stop).**

  (1) Complete remainder of 40-fsw stop on air.

  (2) Ascend to 20 fsw. Repeat the 40-fsw chamber stop time.

  (3) Ascend to 10 fsw. Stay there for twice the 40-fsw chamber stop time.

- **CNS O_2 Toxicity (40-fsw Chamber Stop).**

  (1) Remove the BIBS masks from the divers. Wait for all symptoms to completely subside. Wait an additional 15 minutes. Place the divers back on oxygen and resume the decompression at the point of interruption. The period the divers are not breathing oxygen is considered "dead time" and is not counted toward the total stop time. This procedure can be repeated as many times as the Dive Supervisor considers prudent until all the required time spent breathing oxygen at 40 fsw is met. If the Dive Supervisor decides that the diver just cannot tolerate oxygen:

  (2) Complete remainder of 40-fsw stop on air. Count all the time at 40 fsw toward stop time. If all time at 40 fsw already meets or exceeds the 40-fsw stop time, then ascend to 20 fsw.

  (3) Ascend to 20 fsw. Repeat the 40-fsw chamber stop time.

  (4) Ascend to 10 fsw. Stay there for twice the 40-fsw stop chamber time.

- **Convulsions at the 40-fsw Chamber Stop.**

NOTE

If the first symptom of CNS O_2 toxicity at the 40-fsw stop is a convulsion, oxygen must not be restarted.

  (1) Remove the BIBS mask.

  (2) Keep the chamber depth constant

DIVING CHART - AIR

1Ø44

Date
Ø7 OCT 91

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
HMCS (DV) DOLE	MK 12	Dry Suit/Underwear	
NAME OF DIVER 2 HTC (DV) WESTBROOK	**DIVING APPARATUS** MK 12	**TYPE DRESS** Dry Suit/Underwear	**EGS (PSIG)**

TENDERS (DIVER 1)	TENDERS (DIVER 2)
KASSLER AND ASHLEY	FAWCET AND COPE

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
Ø9ØØ	155 + 2 = 157	~~Ø9Ø3~~	:Ø3
LEFT BOTTOM (LB) Ø94Ø	**TOTAL BOTTOM TIME (TBT)** :4Ø	**TABLE & SCHEDULE USED** 16Ø/4Ø Sur-D O_2	**TIME TO FIRST STOP** :Ø3::3Ø
REACHED SURFACE (RS) 1ØØ1::1Ø/1Ø43::3Ø	**TOTAL DECOMPRESSION TIME (TDT)** 1:Ø3::3Ø	**TOTAL TIME OF DIVE (TTD)** 1:43::3Ø	**REPETITIVE GROUP**

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:Ø1 / 1Ø::2Ø / Ø	10			L R	
	3Ø fpm / :Ø3::3Ø	20			L R	
		30	:Ø8		L 1ØØØ::1Ø R Ø952::1Ø	
	::2Ø / Ø::Ø	40	:Ø5	:3Ø O_2 :Ø5 Air :Ø2 O_2	L Ø951::5Ø R Ø946::5Ø	1Ø42::1Ø 1ØØ5::1Ø
75	::2Ø	50	:Ø3		L Ø946::3Ø R Ø943::3Ø	
fpm	:Ø3::3Ø	60			L R	
		70			L R	
		80			L R	
	4Ø fpm	90			L R	
	3Ø fpm	100			L R	
		110			L R	
		120			L R	
:Ø3		155 ~~130~~			L Ø94Ø R ~~Ø9Ø3~~	

PURPOSE OF DIVE	REMARKS
TRAINING	OK TO REPET
DIVER'S CONDITION OK	**DIVING SUPERVISOR** MDV BROOKS

Figure 7-12.

on air. Count all the time at 40 fsw toward stop time. If all time at 40 fsw already meets or exceeds the 40-fsw stop time, then ascend to 20 fsw.

(4) Ascend to 20 fsw. Repeat the 40-fsw chamber stop time.

(5) Ascend to 10 fsw. Stay there for twice the 40-fsw stop chamber time.

Example: Divers make a planned dive to 157 feet for 40 minutes using the Surface Decompression Table Using Oxygen. From the appropriate schedule (160/40), there is a three-minute water stop at 50 fsw, a five-minute water stop at 40 fsw, an eight-minute water stop at 30 fsw, and a 32-minute chamber stop at 40 fsw breathing oxygen. After 12 minutes of breathing oxygen at the 40-foot chamber stop, a diver develops an oxygen toxicity symptom which completely subsides in five minutes.

Solution: Following the procedures for handling an oxygen toxicity symptom, remove the BIBS from the diver. The diver breathes chamber air until all symptoms completely subside. After an additional 15 minutes, place the diver back on oxygen and continue the decompression schedule from the point of interruption. Figure 7-13 is a profile of this dive.

Example: Divers make a planned dive to 157 feet for 44 minutes using the Surface Decompression Table Using Oxygen. From the appropriate schedule (160/45), there is a three-minute water stop at 60 fsw, a four-minute water stop at 50 fsw, an eight-minute water stop at 40 fsw, a six-minute stop at 30 fsw, and a 38-minute chamber stop at 40 fsw breathing oxygen. After 12 minutes of breathing oxygen at the 40-foot chamber stop, a diver suffers a convulsion. The convulsion completely subsides in five minutes and the diver regains consciousness.

Solution: Following the procedures for handling an oxygen toxicity convulsion, remove the BIBS from the diver. The diver breathes chamber air until all symptoms completely subside and he regains consciousness.

(1) Complete remainder of 40-fsw stop on air.

(2) Ascend to 20 fsw. Repeat the 40-fsw chamber stop time.

(3) Ascend to 10 fsw. Stay there for twice the 40-fsw chamber stop time.

Figure 7-14 is a profile of this dive.

There are no repetitive diving tables or surface interval tables for surface decompression dives. If another surface decompression dive using oxygen is planned within a 12-hour period, the following procedures apply: add the bottom times of all dives made in the previous 12 hours to get an adjusted bottom time, and use the maximum depth obtained in the previous 12 hours to select a decompression schedule.

Example: A dive conducted to 170 fsw for 25 minutes, a surface interval of 3 hours 42 minutes, and a repetitive dive to 138 fsw for 15 minutes using the Surface Decompression Table Using Oxygen for both dives.

Solution: The correct decompression schedule is 170/25 for the first dive and 170/40 for the second dive. Even though the second dive was to a maximum depth of 138 fsw for 15 minutes, the divers must be decompressed for the maximum depth attained in the previous 12 hours, which was 170 fsw, and a total of all bottom times, which was

(1Ø59)

DIVING CHART - AIR

Date 12 OCT 91

NAME OF DIVER 1 BMCM (MDV) Van Dine	DIVING APPARATUS MK 12	TYPE DRESS Dry Suit/Underwear	EGS (PSIG)
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)

TENDERS (DIVER 1) DELAUTER AND WILLIAMS	TENDERS (DIVER 2) AND

LEFT SURFACE (LS) Ø9ØØ	DEPTH (fsw) 155 + 2 : 157	REACHED BOTTOM (RB) ~~Ø9Ø3~~	DESCENT TIME :Ø3
LEFT BOTTOM (LB) Ø94Ø	TOTAL BOTTOM TIME (TBT) :4Ø	TABLE & SCHEDULE USED 16Ø/4Ø Sur-D O_2	TIME TO FIRST STOP Ø3::3Ø
REACHED SURFACE (RS) 1ØØ1::1Ø/1Ø58::3Ø	TOTAL DECOMPRESSION TIME (TDT) 1:18::3Ø	TOTAL TIME OF DIVE (TTD) 1:58::3Ø	REPETITIVE GROUP

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
		10			L R	
		20			L R	
		30	:Ø8		L 1ØØØ::1Ø R Ø952::1Ø	
		40	:Ø5	:12 O_2 :Ø5 Air :15 Air :2Ø O_2	L Ø951::5Ø R Ø946::5Ø	1Ø57::1Ø 1ØØ5::1Ø
		50	:Ø3		L Ø946::3Ø R Ø943::3Ø	
		60			L R	
		70			L R	
		80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
:Ø3		155 ~~130~~			L Ø94Ø R ~~Ø9Ø3~~	

PURPOSE OF DIVE REQUAL	REMARKS O_2 symptom :12 into 4Ø fsw chamber stop. Off O_2. Subsided *
DIVER'S CONDITION OK RED	DIVING SUPERVISOR QMCM (MDV) WILLIAMS

* in :Ø5. Waited :15. Resumed O_2 at point of interruption (:2Ø remaining).

Figure 7-13.

1148

DIVING CHART - AIR

Date 17 OCT 91

NAME OF DIVER 1: DEBOLT	DIVING APPARATUS: MK 12	TYPE DRESS: Dry Suit/Underwear	EGS (PSIG)
NAME OF DIVER 2: MOORE	DIVING APPARATUS: MK 12	TYPE DRESS: Dry Suit/Underwear	EGS (PSIG)
TENDERS (DIVER 1): BOLIVAR AND DELAUTER		TENDERS (DIVER 2): JOHNSON AND DOLE	
LEFT SURFACE (LS): Ø8ØØ	DEPTH (fsw): 155 + 2 = 157	REACHED BOTTOM (RB): ~~Ø8Ø3~~	DESCENT TIME: :Ø3
LEFT BOTTOM (LB): Ø844	TOTAL BOTTOM TIME (TBT): :44	TABLE & SCHEDULE USED: 16Ø/45 Sur-D O_2	TIME TO FIRST STOP: :Ø3::1Ø
REACHED SURFACE (RS): Ø91Ø::1Ø/1147::3Ø	TOTAL DECOMPRESSION TIME (TDT): 3:Ø3::3Ø	TOTAL TIME OF DIVE (TTD): 3:47::3Ø	REPETITIVE GROUP

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:Ø1 / :12	10		:76	L / R	1147::1Ø / 1Ø31::1Ø
	:2Ø / :33::3Ø	20		:38	L / R	1Ø3Ø::5Ø / Ø952::5Ø
	:4Ø / :3Ø / :Ø5+1Ø	30	:Ø6		L Ø9Ø9::1Ø / R Ø9Ø3::1Ø	
75 fpm	:2Ø / :3Ø / 4	40	:Ø8	:12 O_2 :Ø5 Air :21 Air	L Ø9Ø2::5Ø / R Ø854::5Ø	Ø952::1Ø / Ø914::1Ø
	:2Ø	50	:Ø4		L Ø854::3Ø / R Ø85Ø::3Ø	
	:2Ø	60	:Ø3		L Ø85Ø::1Ø / R Ø847::1Ø	
	:Ø3::1Ø	70			L / R	
		80			L / R	
	3Ø fpm	90			L / R	
		100			L / R	
		110			L / R	
		120			L / R	
:Ø3		155 ~~130~~			L Ø844 / R ~~Ø8Ø3~~	

PURPOSE OF DIVE: TRAINING	REMARKS: Red diver O_2 convulsion :12 into 4Ø fsw stop. OK in :Ø5. Completed*
DIVER'S CONDITION: EXAMINED BY DMO; OK	DIVING SUPERVISOR: BMCM (MDV) Van Dine

* decompression according to procedure for oxygen convulsion.

Figure 7-14.

40 minutes. Figures 7-15, 7-16, and 7-17 chart this example.

Even if the second dive is to be a Standard Air dive, combine all bottom times in the previous 12 hours to get an adjusted bottom time and decompression schedule from the maximum depth attained in the previous 12 hours.

7-5.4.2 Surface Decompression Table Using Air. The Surface Decompression Table Using Air (referred to as Sur D Air) should be used for surface decompression following an air dive when a recompression chamber without an oxygen breathing system is all that is available.

The total ascent times of the Surface Decompression Table Using Air exceed those of the Standard Air Decompression Table; the only advantages of using this table are getting the divers out of the water sooner than if they were decompressing on the Standard Air Table, and maintaining the divers in a controlled, closely observed environment during decompression.

When using the Sur D Air table, all ascents are made at 30 fpm. This includes the ascent rate from the last water stop. The time spent on the surface should not exceed 3 ½ minutes and the rate of descent to the first recompression chamber stop should not exceed 60 fpm. **The total elapsed time for these three procedures must not exceed five minutes.**

If the prescribed surface interval is exceeded and the divers are asymptomatic, they are treated as if they had Type I Decompression Sickness (Treatment Table 5, Chapter 8). If the divers are symptomatic, they are treated as if they had Type II Decompression Sickness (Treatment Table 6, Chapter 8), even if they are only displaying Type I symptoms. **Symptoms occurring during the chamber stops are treated as recurrences (Chapter 8).**

Example: A dive conducted to 128 fsw for 48 minutes using the Surface Decompression Table Using Air would use the schedule shown in the solution below.

Solution: The correct decompression schedule for a dive conducted to 128 feet for 48 minutes is the 130/50 schedule. The decompression chart is shown in Figure 7-18.

If a second surface decompression air dive is planned within a 12-hour period, the same rule applies for making a second Sur D O_2 dive (Paragraph 7-5.4).

Example: A repetitive Sur D Air dive is planned for 143 fsw for 20 minutes. The previous dive was to 172 fsw for 30 minutes. The surface interval was 4 hours 27 minutes.

Solution: The correct schedule for the first dive is 180/30. The correct schedule for the second dive is 180/50. As explained in the Sur D O_2 procedure, the correct procedure is to decompress the divers on a schedule for the maximum depth attained and the total of bottom times of all dives made in the previous 12 hours. In this example, the divers could make a third surface decompression air dive as long as the maximum depth did not exceed 190 fsw, or the bottom time did not exceed 10 minutes. They would then be decompressed on the 190/60 Sur D Air schedule. Figures 7-19, 7-20, and 7-21 illustrate the first dive, the repetitive dive worksheet and the repetitive dive for the example above.

7-5.5 Exceptional Exposure Dives. The Exceptional Exposure air decompression schedules (printed in red) presented in the Standard Air Decompression Table are for dives which expose the diver to oxygen partial pressures and environmental conditions considered severe by U.S. Navy standards. The long decompressions, which must be carried out in the water, impose unusual demands on a diver's endurance. De-

~~Ø855~~ Ø855

DIVING CHART - AIR

Date 26 SEP 91

NAME OF DIVER 1 DR. HARVEY	DIVING APPARATUS MK 12	TYPE DRESS Dry Suit/Underwear	EGS (PSIG)
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
TENDERS (DIVER 1) DELAUTER AND BROOKS		TENDERS (DIVER 2) AND	
LEFT SURFACE (LS) Ø800	DEPTH (fsw) 168 + 2 = 17Ø	REACHED BOTTOM (RB) ~~Ø8Ø3~~	DESCENT TIME :Ø3
LEFT BOTTOM (LB) Ø825	TOTAL BOTTOM TIME (TBT) :25	TABLE & SCHEDULE USED 17Ø/25 Sur-D O_2	TIME TO FIRST STOP :Ø5::36
REACHED SURFACE (RS) Ø83Ø::36/Ø854::56	TOTAL DECOMPRESSION TIME (TDT) :29::56	TOTAL TIME OF DIVE (TTD) :54::56	REPETITIVE GROUP

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:Ø5::36 :Ø1 :2Ø	10			L R	
	3Ø fpm	20			L R	
	:Ø::3Ø 3Ø fpm	30			L R	
	+::3Ø :Ø4	40		On O_2 :19	L R	Ø853::36 Ø834::36
75 fpm		50			L R	
		60			L R	
		70			L R	
		80			L R	
	3Ø fpm	90			L R	
		100			L R	
		110			L R	
		120			L R	
:Ø3		168 ~~130~~			L Ø825 R ~~Ø8Ø3~~	

PURPOSE OF DIVE REQUAL	REMARKS OK TO REPET
DIVER'S CONDITION OK RED	DIVING SUPERVISOR LT JOHNSON

Figure 7-15.

REPETITIVE DIVE WORKSHEET

DATE 26 SEP 91

1. PREVIOUS DIVE:

25 minutes ☐ Standard Air Table ☐ No-Decompression Table

168 + 2 = 170 feet ☑ Surface Table Using Oxygen ☐ Surface Table Using Air

_____ repetitive group letter designation

2. SURFACE INTERVAL:

3 hours 42 minutes on surface

_____ repetitive group from item 1 above

_____ new repetitive group letter designation from Residual Nitrogen Timetable

3. RESIDUAL NITROGEN TIME:

138 + ___ = ___ feet, depth of repetitive dive

_____ new repetitive group letter designation from item 2 above

25 minutes, residual nitrogen time from Residual Nitrogen Timetable or bottom time of previous Sur D dive

4. EQUIVALENT SINGLE DIVE TIME:

25 minutes, residual nitrogen time from item 3 above or bottom time of previous Sur D dive

+ 15 minutes, actual bottom time of repetitive dive

= 40 minutes, equivalent single dive time

5. DECOMPRESSION FOR REPETITIVE DIVE:

138 + ___ = ___ feet, depth of repetitive dive Previous dive was 168 + 2 = 170 feet

40 minutes, equivalent single dive time from item 4 above

Decompression from (check one):

☐ Standard Air Table ☐ No-Decompression Table

☑ Surface Table Using Oxygen ☐ Surface Table Using Air

Decompression Stops:	Depth		Water		Chamber	
	30	feet	6	minutes		minutes
	40	feet	8	minutes	36	minutes
	50	feet	4	minutes		minutes
	60	feet	4	minutes		minutes
		feet		minutes		minutes

170/40 schedule used (depth/time)

_____ repetitive group letter designation (Diver "Maxed Out" On Sur-D O_2)

Figure 7-16.

Sur-D O_2 Repet. Do Not Repet.

DIVING CHART - AIR 1405

Date 26 SEP 91

NAME OF DIVER 1 DR. HARVEY	DIVING APPARATUS MK 12	TYPE DRESS Dry Suit/Underwear	EGS (PSIG)
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)

TENDERS (DIVER 1) BROOKS AND DELAUTER		TENDERS (DIVER 2) AND	
LEFT SURFACE (LS) 1237	DEPTH (fsw) 136 + 2 = 138	REACHED BOTTOM (RB) ~~1239~~	DESCENT TIME :02
LEFT BOTTOM (LB) 1252	TOTAL BOTTOM TIME (TBT) :15 + :25 = :40	TABLE & SCHEDULE USED 170/40 Sur-D O_2	TIME TO FIRST STOP :02::32
REACHED SURFACE (RS) 1318::36/1404::56	TOTAL DECOMPRESSION TIME (TDT) 1:12::56	TOTAL TIME OF DIVE (TTD) 1:27::56	REPETITIVE GROUP

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:01 :01::20 30 fpm	10			L R	
	30 fpm	20			L R	
	:03::30 :30::30 30 fpm	30	:06		L 1317::36 R 1311::36	
75 fpm	:20 :40	40	:08	:30 O_2 :05 Air :06 O_2	L 1311::16 R 1303::16	1403::36 1322::36
	:20	50	:04		L 1302::56 R 1258::56	
	:20	60	:04		L 1258::32 R 1254::32	
	:02::32	70			L R	
		80			L R	
		90			L R	
	30 fpm	100			L R	
		110			L R	
		120			L R	
:02		136 ~~130~~			L 1252 R ~~1239~~	

PURPOSE OF DIVE TRAINING	REMARKS DO NOT REPET. MAXED OUT SUR-D O_2.
DIVER'S CONDITION OK RED	DIVING SUPERVISOR LT BOLIVAR

Figure 7-17.

DIVING CHART - AIR

1244

Date	18 OCT 91

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
CDR SAWYER	MK 12	Dry Suit/Underwear	
NAME OF DIVER 2	**DIVING APPARATUS**	**TYPE DRESS**	**EGS (PSIG)**

TENDERS (DIVER 1)	TENDERS (DIVER 2)
BMCM(MW) Van Dive AND GMCM(MDV) Brooks	AND

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
1φ25	126 + 2 = 128	~~1φ27~~	:φ2
LEFT BOTTOM (LB)	**TOTAL BOTTOM TIME (TBT)**	**TABLE & SCHEDULE USED**	**TIME TO FIRST STOP**
1113	:48	130/50 Sur-D Air	:φ3::12
REACHED SURFACE (RS)	**TOTAL DECOMPRESSION TIME (TDT)**	**TOTAL TIME OF DIVE (TTD)**	**REPETITIVE GROUP**
1141::12/1243::42	1:3φ::42	2:18::42	

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER		TIME WATER	TIME CHAMBER
	::40	10		:37	L		1243::22
					R		12φ6::22
		20	:21	:21	L	114φ::32	12φ6::φ2
					R	1119::32	1145::φ2
	::2φ 60 fpm	30	:φ3		L	1119::12	
					R	1116::12	
75 fpm	:φ3::12	40			L		
					R		
		50			L		
					R		
		60			L		
					R		
		70			L		
					R		
		80			L		
					R		
	30 fpm	90			L		
					R		
		100			L		
					R		
		110			L		
					R		
		120			L		
					R		
:φ2		126			L	1113	
		~~130~~			R	~~1φ27~~	

PURPOSE OF DIVE	REMARKS
SEARCH PROJECT	Sur-D Air. Ok To Repet.
DIVER'S CONDITION	**DIVING SUPERVISOR**
OK RED	SMCM (MDV) DELAUTER

Figure 7-18.

1548

DIVING CHART - AIR

Date: Ø1 OCT 91

NAME OF DIVER 1: HTC (DV) WESTBROOK	DIVING APPARATUS: MK 12	TYPE DRESS: Dry Suit/Underwear	EGS (PSIG)
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)

TENDERS (DIVER 1): HOWLE AND BOHANNON		TENDERS (DIVER 2): AND	
LEFT SURFACE (LS): 14ØØ	DEPTH (fsw): 17Ø + 2 = 172	REACHED BOTTOM (RB): ~~14Ø3~~	DESCENT TIME: :Ø3
LEFT BOTTOM (LB): 143Ø	TOTAL BOTTOM TIME (TBT): :3Ø	TABLE & SCHEDULE USED: 18Ø/3Ø Sur-D Air	TIME TO FIRST STOP: :Ø4::4Ø
REACHED SURFACE (RS): 1458::4Ø/1547::1Ø	TOTAL DECOMPRESSION TIME (TDT): 1:17::1Ø	TOTAL TIME OF DIVE (TTD): 1:47::1Ø	REPETITIVE GROUP

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER		TIME WATER	TIME CHAMBER
		10		:27	L		1546::5Ø
					R		1519::5Ø
		20	:17	:17	L	1458	1519::3Ø
					R	1441	15Ø2::3Ø
		30	:Ø6		L	144Ø::4Ø	
					R	1434::4Ø	
		40			L		
					R		
		50			L		
					R		
		60			L		
					R		
		70			L		
					R		
		80			L		
					R		
		90			L		
					R		
		100			L		
					R		
		110			L		
					R		
		120			L		
					R		
:Ø3		17Ø ~~130~~			L	143Ø	
					R	~~14Ø3~~	

PURPOSE OF DIVE: SURVEY CRASH DEBRIS	REMARKS: Sur-D Air. Ok to Repet.
DIVER'S CONDITION: OK RED	DIVING SUPERVISOR: HTCM (MDV) De Bolt.

Figure 7-19.

REPETITIVE DIVE WORKSHEET

DATE 1 OCT 91

1. PREVIOUS DIVE:

30 minutes ☐ Standard Air Table ☐ No-Decompression Table

172 + ____ = ____ feet ☐ Surface Table Using Oxygen ☑ Surface Table Using Air

____ repetitive group letter designation

2. SURFACE INTERVAL:

4 hours 27 minutes on surface

____ repetitive group from item 1 above

____ new repetitive group letter designation from Residual Nitrogen Timetable

3. RESIDUAL NITROGEN TIME:

143 + ____ = ____ feet, depth of repetitive dive

____ new repetitive group letter designation from item 2 above

30 minutes, residual nitrogen time from Residual Nitrogen Timetable or bottom time of previous Sur D dive

4: EQUIVALENT SINGLE DIVE TIME:

30 minutes, residual nitrogen time from item 3 above or bottom time of previous Sur D dive

\+ 20 minutes, actual bottom time of repetitive dive

= 50 minutes, equivalent single dive time

5. DECOMPRESSION FOR REPETITIVE DIVE:

143 + ____ = ____ feet, depth of repetitive dive Previous dive was 172 feet.

50 minutes, equivalent single dive time from item 4 above

Decompression from (check one):

☐ Standard Air Table ☐ No-Decompression Table

☐ Surface Table Using Oxygen ☑ Surface Table Using Air

Decompression Stops:

Depth	Water	Chamber
10 feet	— minutes	65 minutes
20 feet	30 minutes	30 minutes
30 feet	19 minutes	____ minutes
40 feet	9 minutes	____ minutes
50 feet	2 minutes	____ minutes

180/50 schedule used (depth/time)

____ repetitive group letter designation

Figure 7-20.

DIVING CHART - AIR

2320

Date
Ø1 OCT 91

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
HTC (DV) WESTBROOK			
NAME OF DIVER 2	**DIVING APPARATUS**	**TYPE DRESS**	**EGS (PSIG)**

TENDERS (DIVER 1)		TENDERS (DIVER 2)	
BOLIVAR AND JOHNSON		AND	
LEFT SURFACE (LS)	**DEPTH (fsw)**	**REACHED BOTTOM (RB)**	**DESCENT TIME**
2Ø15	(141) + 2 = 143	~~2Ø17~~	:Ø2
LEFT BOTTOM (LB)	**TOTAL BOTTOM TIME (TBT)**	**TABLE & SCHEDULE USED**	**TIME TO FIRST STOP**
2Ø35	(:2Ø) + :3Ø = :5Ø	15Ø/5Ø Sur-D Air	:Ø3::Ø2
REACHED SURFACE (RS)	**TOTAL DECOMPRESSION TIME (TDT)**	**TOTAL TIME OF DIVE (TTD)**	**REPETITIVE GROUP**
2139::42/2319::12	2:44::12	3:Ø4::12	

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:4Ø :2Ø Fpm	10		:65	L R	L 2318::52 R 2213::52
	:3Ø :2Ø 3Ø	20	:3Ø	:3Ø	L 2139::Ø2 R 21Ø9::Ø2	L 2213::32 R 2143::32
	:2Ø :3Ø 6Ø Fpm	30	:19		L 21Ø8::42 R 2Ø49::42	L R
75	:2Ø :2Ø	40	:Ø9		L 2Ø49::22 R 2Ø4Ø::22	L R
Fpm	:2Ø 2 :Ø	50	:Ø2		L 2Ø4Ø::Ø2 R 2Ø38::Ø2	
	:Ø3 :5Ø	60			L R	
		70			L R	
		80			L R	
	4Fpm	90			L R	
	3Ø	100			L R	
		110			L R	
		120			L R	
:Ø2		141 ~~130~~			L 2Ø35 R ~~2Ø17~~	

PURPOSE OF DIVE	REMARKS
RECOVER DEBRIS	SUR-D AIR. OK To Repet.
DIVER'S CONDITION	**DIVING SUPERVISOR**
OK RED	SMCM (MDV) DECAUTER

Figure 7-21.

compression conducted according to these schedules have limited assurance that they will be completed without incidence of decompression sickness. The Commanding Officer must assess the need for conducting an exceptional exposure dive and prior CNO approval is required. **Exceptional exposure dives** should **only be conducted in an emergency.** This is not to say that circumstances cannot arise which would necessitate using the Exceptional Exposure schedule (diver entrapment, etc.), but **exceptional exposure dives** should **not be planned.** Selected exceptional exposure dives have been proven safe in controlled conditions and are authorized at the Naval Diving and Salvage Training Center during certain phases of diver training.

7-6 DIVING AT ALTITUDE AND FLYING AFTER DIVING

7-6.1 Air Decompression Tables. All air decompression tables in this chapter may be used in fresh water at altitudes up to 2,300 feet (700 meters). The following provisions apply:

- Some pressure gauges do not compensate for altitude and will read absolute pressure, so a table chosen based on a depth gauge reading will be shallower than that chosen by actually measuring depth. Choose a decompression table based on the actual measured depth, not the depth from a depth gauge. Thus, a table will be chosen as if the divers made a dive to the same measured depth in seawater. If there is any doubt about the depth accuracy, go to the next deeper table.

- Use a decompression line for decompression stops, and measure stop depths from the surface. All stop depths should be increased one foot to compensate for the lower density of fresh water. Therefore, last stop will be at 11 feet.

NAVSEA (00C) must give prior approval for diving operations which are to be conducted at altitudes greater than 2,300 feet above sea level. NAVSEA (OOC) will provide altitude dive tables when authorization is granted.

7-6.2 Flying After Diving. Divers should not fly for 12 hours after surfacing from a decompression dive or for two hours following a no-decompression dive. If aircraft cabin pressure is maintained below 2,300 feet altitude, then flying may be done immediately after any air dive.

Table 7-3. No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Air Dives.

Depth (feet/meters)		No-Decompression Limits (min)	Group Designation														
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10	3.0		60	120	210	300											
15	4.6		35	70	110	160	225	350									
20	6.1		25	50	75	100	135	180	240	325							
25	7.6		20	35	55	75	100	125	160	195	245	315					
30	9.1		15	30	45	60	75	95	120	145	170	205	250	310			
35	10.7	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270	310
40	12.2	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200	
50	15.2	100		10	15	25	30	40	50	60	70	80	90	100			
60	18.2	60		10	15	20	25	30	40	50	55	60					
70	21.3	50		5	10	15	20	30	35	40	45	50					
80	24.4	40		5	10	15	20	25	30	35	40						
90	27.4	30		5	10	12	15	20	25	30							
100	30.5	25		5	7	10	15	20	22	25							
110	33.5	20			5	10	13	15	20								
120	36.6	15			5	10	12	15									
130	39.6	10			5	8	10										
140	42.7	10			5	7	10										
150	45.7	5			5												
160	48.8	5				5											
170	51.8	5				5											
180	54.8	5				5											
190	59.9	5				5											

Table 7-4. Residual Nitrogen Timetable for Repetitive Air Dives.

Locate the diver's repetitive group designation from his previous dive along the diagonal line above the table. Read horizontally to the interval in which the diver's surface interval lies.

Next read vertically downward to the new repetitive group designation. Continue downward in this same column to the row which represents the depth of the repetitive dive. The time given at the intersection is residual nitrogen time, in minutes, to be applied to the repetitive dive.

* Dives following surface intervals of more than 12 hours are not repetitive dives. Use actual bottom times in the Standard Air Decompression Tables to compute decompression for such dives.

** If no Residual Nitogen Time is given, then the repetitive group does not change.

Changes based on NEDU Report 13-83

Repetitive group at the beginning of the surface interval

Group	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
A																0:10 12:00*
B															0:10 3:20	3:21 12:00*
C														0:10 1:39	1:40 4:49	4:50 12:00*
D													0:10 1:09	1:10 2:38	2:39 5:48	5:49 12:00*
E												0:10 0:54	0:55 1:57	1:58 3:24	3:25 6:34	6:35 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*
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*
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*
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*
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 8:50	8:51 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*
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*
M				0:10 0:25	0:26 0:42	0:43 0:59	1:00 1:18	1:19 1:35	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*
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*
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*
Z	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	10:06 12:00*

NEW GROUP DESIGNATION

Repetitive Dive Depth feet	meters	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
10	3.0	**	**	**	**	**	**	**	**	**	**	**	**	279	159	88	39
20	6.1	**	**	**	**	**	**	**	399	279	208	159	120	88	62	39	18
30	9.1	**	**	469	349	279	229	190	159	132	109	88	70	54	39	25	12
40	12.2	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	15.2	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
60	18.2	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	21.3	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	24.4	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	27.4	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	3
100	30.5	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	33.5	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	36.6	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3
130	39.6	46	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3
140	42.7	42	40	38	35	32	29	26	23	20	18	15	12	10	7	5	2
150	45.7	40	38	35	32	30	27	24	22	19	17	14	12	9	7	5	2
160	48.8	37	36	33	31	28	26	23	20	18	16	13	11	9	6	4	2
170	51.8	35	34	31	29	26	24	22	19	17	15	12	10	8	6	4	2
180	54.8	32	31	29	27	25	22	20	18	16	14	11	10	8	6	4	2
190	59.9	31	30	28	26	24	21	19	17	15	13	10	10	8	6	4	2

Residual Nitrogen Times (Minutes)

Table 7-5. U.S. Navy Standard Air Decompression Table.

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)	Repetitive group
40 / 12.1	200						0	0:40	*
	210	1:00					2	2:40	N
	230	1:00					7	7:40	N
	250	1:00					11	11:40	O
	270	1:00					15	15:40	O
	300	1:00					19	19:40	Z
	360	1:00					23	23:40	**
	480	1:00					41	41:40	**
	720	1:00					69	69:40	**
50 / 15.2	100						0	0:50	*
	110	1:20					3	3:50	L
	120	1:20					5	5:50	M
	140	1:20					10	10:50	M
	160	1:20					21	21:50	N
	180	1:20					29	29:50	O
	200	1:20					35	35:50	O
	220	1:20					40	40:50	Z
	240	1:20					47	47:50	Z
60 / 18.2	60						0	1:00	*
	70	1:40					2	3:00	K
	80	1:40					7	8:00	L
	100	1:40					14	15:00	M
	120	1:40					26	27:00	N
	140	1:40					39	40:00	O
	160	1:40					48	49:00	Z
	180	1:40					56	57:00	Z
	200	1:20				1	69	71:00	Z
	240	1:20				2	79	82:00	**
	360	1:20				20	119	140:00	**
	480	1:20				44	148	193:00	**
	720	1:20				78	187	266:00	**
70 / 21.3	50						0	1:10	*
	60	2:00					8	9:10	K
	70	2:00					14	15:10	L
	80	2:00					18	19:10	M
	90	2:00					23	24:10	N
	100	2:00					33	34:10	N
	110	1:40				2	41	44:10	O
	120	1:40				4	47	52:10	O
	130	1:40				6	52	59:10	O
	140	1:40				8	56	65:10	Z
	150	1:40				9	61	71:10	Z
	160	1:40				13	72	86:10	Z
	170	1:40				19	79	99:10	Z

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 7-5. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/ meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 50 15.2	40 12.1	30 9.1	20 6.0	10 3.0	Total decompression time (min:sec)	Repetitive group
80 **24.3**	40						0	1:20	*
	50	2:20					10	11:20	K
	60	2:20					17	18:20	L
	70	2:20					23	24:20	M
	80	2:00				2	31	34:20	N
	90	2:00				7	39	47:20	N
	100	2:00				11	46	58:20	O
	110	2:00				13	53	67:20	O
	120	2:00				17	56	74:20	Z
	130	2:00				19	63	83:20	Z
	140	2:00				26	69	96:20	Z
	150	2:00				32	77	110:20	Z
	180	2:00				35	85	121:20	**
	240	1:40			6	52	120	179:20	**
	360	1:40			29	90	160	280:20	**
	480	1:40			59	107	187	354:20	**
	720	1:20		17	108	142	187	455:20	**
90 **28.7**	30						0	1:30	*
	40	2:40					7	8:30	J
	50	2:40					18	19:30	L
	60	2:40					25	26:30	M
	70	2:20				7	30	38:30	N
	80	2:20				13	40	54:30	N
	90	2:20				18	48	67:30	O
	100	2:20				21	54	76:30	Z
	110	2:20				24	61	86:30	Z
	120	2:20				32	68	101:30	Z
	130	2:00			5	36	74	116:30	Z
100 **30.4**	25						0	1:40	*
	30	3:00					3	4:40	I
	40	3:00					15	16:40	K
	50	2:40				2	24	27:40	L
	60	2:40				9	28	38:40	N
	70	2:40				17	39	57:40	O
	80	2:40				23	48	72:40	O
	90	2:20			3	23	57	84:40	Z
	100	2:20			7	23	66	97:40	Z
	110	2:20			10	34	72	117:40	Z
	120	2:20			12	41	78	132:40	Z
	180	2:00		1	29	53	118	202:40	**
	240	2:00		14	42	84	142	283:40	**
	360	1:40	2	42	73	111	187	416:40	**
	480	1:40	21	61	91	142	187	503:40	**
	720	1:40	55	106	122	142	187	613:40	**

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 7-5. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/ meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 50	40	30	20	10	Total decompression time (min:sec)	Repetitive group
			15.2	12.1	9.1	6.0	3.0		
110 **33.1**	20						0	1:50	*
	25	3:20					3	4:50	H
	30	3:20					7	8:50	J
	40	3:00				2	21	24:50	L
	50	3:00				8	26	35:50	M
	60	3:00				18	36	55:50	N
	70	2:40			1	23	48	73:50	O
	80	2:40			7	23	57	88:50	Z
	90	2:40			12	30	64	107:50	Z
	100	2:40			15	37	72	125:50	Z

Depth	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 70	60	50	40	30	20	10	Total decompression time (min:sec)	Repetitive group
			21.3	18.2	15.2	12.1	9.1	6.0	3.0		
120 **36.5**	15								0	2:00	*
	20	3:40							2	4:00	H
	25	3:40							6	8:00	I
	30	3:40							14	16:00	J
	40	3:20						5	25	32:00	L
	50	3:20						15	31	48:00	N
	60	3:00					2	22	45	71:00	O
	70	3:00					9	23	55	89:00	O
	80	3:00					15	27	63	107:00	Z
	90	3:00					19	37	74	132:00	Z
	100	3:00					23	45	80	150:00	Z
	120	2:40				10	19	47	98	176:00	**
	180	2:20			5	27	37	76	137	284:00	**
	240	2:20			23	35	60	97	179	396:00	**
	360	2:00		18	45	64	93	142	187	551:00	**
	480	1:40	3	41	64	93	122	142	187	654:00	**
	720	1:40	32	74	100	114	122	142	187	773:00	**

Depth	Bottom time (min)	Time first stop (min:sec)	70	60	50	40	30	20	10	Total decompression time (min:sec)	Repetitive group
130 **39.6**	10								0	2:10	*
	15	4:00							1	3:10	F
	20	4:00							4	6:10	H
	25	4:00							10	12:10	J
	30	3:40						3	18	23:10	M
	40	3:40						10	25	37:10	N
	50	3:20					3	21	37	63:10	O
	60	3:20					9	23	52	86:10	Z
	70	3:20					16	24	61	103:10	Z
	80	3:00				3	19	35	72	131:10	Z
	90	3:00				8	19	45	80	154:10	Z

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 7-5. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 90 / 27.4	80 / 24.3	70 / 21.3	60 / 18.2	50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)	Repetitive group
140 **42.6**	10										0	2:20	*
	15	4:20									2	4:20	G
	20	4:20									6	8:20	I
	25	4:00								2	14	18:20	J
	30	4:00								5	21	28:20	K
	40	3:40							2	16	26	46:20	N
	50	3:40							6	24	44	76:20	O
	60	3:40							16	23	56	97:20	Z
	70	3:20						4	19	32	68	125:20	Z
	80	3:20						10	23	41	79	155:20	Z
	90	3:00					2	14	18	42	88	166:20	**
	120	3:00					12	14	36	56	120	240:20	**
	180	2:40				10	26	32	54	94	168	386:20	**
	240	2:20			8	28	34	50	78	124	187	511:20	**
	360	2:00		9	32	42	64	84	122	142	187	684:20	**
	480	2:00		31	44	59	100	114	122	142	187	801:20	**
	720	1:40	16	56	88	97	100	114	122	142	187	924:20	**
150 **45.7**	5										0	2:30	C
	10	4:40									1	3:30	E
	15	4:40									3	5:30	G
	20	4:20								2	7	11:30	H
	25	4:20								4	17	23:30	K
	30	4:20								8	24	34:30	L
	40	4:00							5	19	33	59:30	N
	50	4:00							12	23	51	88:30	O
	60	3:40						3	19	26	62	112:30	Z
	70	3:40						11	19	39	75	146:30	Z
	80	3:20					1	17	19	50	84	173:30	Z
160 **48.7**	5										0	2:40	D
	10	5:00									1	3:40	F
	15	4:40								1	4	7:40	H
	20	4:40								3	11	16:40	J
	25	4:40								7	20	29:40	K
	30	4:20							2	11	25	40:40	M
	40	4:20							7	23	39	71:40	N
	50	4:00						2	16	23	55	98:40	Z
	60	4:00						9	19	33	69	132:40	Z
	70	3:40					1	17	22	44	80	166:40	**

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 7-5. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 110 / 33.5	100 / 30.4	90 / 27.4	80 / 24.3	70 / 21.3	60 / 18.2	50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)	Repetitive group
170 / 51.8	5												0	2:50	D
	10	5:20											2	4:50	F
	15	5:00										2	5	9:50	H
	20	5:00										4	15	21:50	J
	25	4:40									2	7	23	34:50	L
	30	4:40									4	13	26	45:50	M
	40	4:20								1	10	23	45	81:50	O
	50	4:20								5	18	23	61	109:50	Z
	60	4:00							2	15	22	37	74	152:50	Z
	70	4:00							8	17	19	51	86	183:50	**
	90	3:40						12	12	14	34	52	120	246:50	**
	120	3:00				2	10	12	18	32	42	82	156	356:50	**
	180	2:40			4	10	22	28	34	50	78	120	187	535:50	**
	240	2:40			18	24	30	42	50	70	116	142	187	681:50	**
	360	2:20		22	34	40	52	60	98	114	122	142	187	873:50	**
	480	2:00	14	40	42	56	91	97	100	114	122	142	187	1007:50	**
180 / 54.8	5												0	3:00	D
	10	5:40											3	6:00	F
	15	5:20										3	6	12:00	I
	20	5:00									1	5	17	26:00	K
	25	5:00									3	10	24	40:00	L
	30	5:00									6	17	27	53:00	N
	40	4:40								3	14	23	50	93:00	O
	50	4:20							2	9	19	30	65	128:00	Z
	60	4:20							5	16	19	44	81	168:00	Z
190 / 57.9	5	5:40											0	3:10	D
	10	5:40										1	3	7:10	G
	15	5:40										4	7	14:10	I
	20	5:20									2	6	20	31:10	K
	25	5:20									5	11	25	44:10	M
	30	5:00								1	8	19	32	63:10	N
	40	5:00								8	14	23	55	103:10	O
	50	4:40							4	13	22	33	72	147:10	**
	60	4:40							10	17	19	50	84	183:10	**

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 7-5. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 130	120	110	100	90	80	70	60	50	40	30	20	10	Total decompression time (min:sec)
			39.6	36.5	33.5	30.4	27.4	24.3	21.3	18.2	15.2	12.1	9.1	6.0	3.0	
200 **60.9**	5	6:20													1	4:20
	10	6:00												1	4	8:20
	15	5:40											1	4	10	18:20
	20	5:40											3	7	27	40:20
	25	5:40											7	14	25	49:20
	30	5:20										2	9	22	37	73:20
	40	5:00									2	8	17	23	59	112:20
	50	5:00									6	16	22	39	75	161:20
	60	4:40								2	13	17	24	51	89	199:20
	90	3:40					1	10	10	12	12	30	38	74	134	324:20
	120	3:20				6	10	10	10	24	28	40	64	98	180	473:20
	180	2:40		1	10	10	18	24	24	42	48	70	106	142	187	685:20
	240	2:40		6	20	24	24	36	42	54	68	114	122	142	187	842:20
	360	2:20	12	22	36	40	44	56	82	98	100	114	122	142	187	1058:20
210 **64.0**	5	6:40													1	4:30
	10	6:20												2	4	9:30
	15	6:00											1	5	13	22:30
	20	6:00											4	10	23	40:30
	25	5:40										2	7	17	27	56:30
	30	5:40										4	9	24	41	81:30
	40	5:20									4	9	19	26	63	124:30
	50	5:20								1	9	17	19	45	80	174:30
220 **67.0**	5	7:00													1	5:40
	10	6:40												2	5	10:40
	15	6:20											2	5	16	26:40
	20	6:00										1	3	11	24	42:40
	25	6:00										3	8	19	33	66:40
	30	5:40									1	7	10	23	47	91:40
	40	5:40									6	12	22	29	68	140:40
	50	5:20								3	12	17	18	51	86	190:40

Table 7-5. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	130 / 39.6	120 / 36.5	110 / 33.5	100 / 30.4	90 / 27.4	80 / 24.3	70 / 21.3	60 / 18.2	50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)
			Decompression stops (feet/meters)													
230 / **70.1**	5	7:20													2	5:50
	10	6:20											1	2	6	12:50
	15	6:20											3	6	18	30:50
	20	6:20										2	5	12	26	48:50
	25	6:20										4	8	22	37	74:50
	30	6:00									2	8	12	23	51	99:50
	40	5:40								1	7	15	22	34	74	156:50
	50	5:40								5	14	16	24	51	89	202:50
240 / **73.1**	5	7:40													2	6:00
	10	7:00											1	3	6	14:00
	15	7:00											4	6	21	35:00
	20	6:40										3	6	15	25	53:00
	25	6:20									1	4	9	24	40	82:00
	30	6:20									4	8	15	22	56	109:00
	40	6:00								3	7	17	22	39	75	167:00
	50	5:40							1	8	15	16	29	51	94	218:00

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	200 / 60.9	190 / 57.9	180 / 54.8	170 / 51.8	160 / 48.7	150 / 45.7	140 / 42.6	130 / 39.6	120 / 36.5	110 / 33.5	100 / 30.4	90 / 27.4	80 / 24.3	70 / 21.3	60 / 18.2	50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)
			Decompression stops (feet/meters)																				
250 / **76.2**	5	7:40																			1	2	7:10
	10	7:20																		1	4	7	16:10
	15	7:00																	1	4	7	22	38:10
	20	7:00																	4	7	17	27	59:10
	25	6:40																2	7	10	24	45	92:10
	30	6:40																6	7	17	23	59	116:10
	40	6:20															5	9	17	19	45	79	178:10
	60	5:20												4	10	10	10	12	22	36	64	164	298:10
	90	4:20									8	10	10	10	10	10	28	28	44	68	98	186	514:10
	120	3:40							5	10	10	10	10	16	24	24	36	48	64	94	142	187	684:10
	180	3:00					4	8	8	10	22	24	24	32	42	44	60	84	114	122	142	187	931:10
	240	3:00					9	14	21	22	22	40	40	42	56	76	98	100	114	122	142	187	1109:10

Table 7-5. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 200 / 60.9	190 / 57.9	180 / 54.8	170 / 51.8	160 / 48.7	150 / 45.7	140 / 42.6	130 / 39.6	120 / 36.5	110 / 33.5	100 / 30.4	90 / 27.4	80 / 24.3	70 / 21.3	60 / 18.2	50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)
260 / 79.2	5	8:00																			1	2	7:20
	10	7:40																		2	4	9	19:20
	15	7:20																	2	4	10	22	42:20
	20	7:00																1	4	7	20	31	67:20
	25	7:00																3	8	11	23	50	99:20
	30	6:40															2	6	8	19	26	61	126:20
	40	6:20														1	6	11	16	19	49	84	190:20
270 / 82.3	5	8:20																			1	3	8:30
	10	8:00																		2	5	11	22:30
	15	7:40																	3	4	11	24	46:30
	20	7:20																2	3	9	21	35	74:30
	25	7:00															2	3	8	13	23	53	106:30
	30	7:00															3	6	12	22	27	64	138:30
	40	6:40														5	6	11	17	22	51	88	204:30
280 / 85.3	5	8:40																			2	2	8:40
	10	8:00																	1	2	5	13	25:40
	15	7:40																1	3	4	11	20	49:40
	20	7:40																3	4	8	23	39	81:40
	25	7:20															2	5	7	16	23	56	113:40
	30	7:00														1	3	7	13	22	30	70	150:40
	40	6:40													1	6	6	13	17	27	51	93	218:40
290 / 88.4	5	9:00																			2	3	9:50
	10	8:20																	1	3	5	16	29:50
	15	8:00																1	3	6	12	26	52:50
	20	8:00																3	7	9	23	43	89:50
	25	7:40															3	5	8	17	23	60	120:50
	30	7:20														1	5	6	16	22	36	72	162:50
	40	7:00													3	5	7	15	16	32	51	95	228:50
300 / 91.4	5	9:20																			3	3	11:00
	10	8:40																	1	3	6	17	32:00
	15	8:20																2	3	6	15	26	57:00
	20	8:00															2	3	7	10	23	47	97:00
	25	7:40														1	3	6	8	19	26	61	129:00
	30	7:40														2	5	7	17	22	39	75	172:00
	40	7:20													4	6	9	15	17	34	51	90	231:00
	60	6:00									4	10	10	10	10	10	14	28	32	50	90	187	460:00
	90	4:40					3	8	8	10	10	10	10	16	24	24	34	48	64	90	142	187	693:00
	120	4:00			4	8	8	8	8	10	14	24	24	24	34	42	58	66	102	122	142	187	890:00
	180	3:30	6	8	8	8	14	20	21	21	28	40	40	48	56	82	98	100	114	122	142	187	1168:00

Table 7-6. Surface Decompression Table Using Oxygen.

Depth feet meters	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) breathing air at water stops (feet/meters) 60 / 18.2	50 / 15.2	40 / 12.1	30 / 9.1	Surface Interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompression time (min:sec)
70 / 21.3	52	2:20					TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		1-MINUTE 20 SECONDS ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	2:20
	90	2:20						15		22:40
	120	2:20						23		30:40
	150	2:20						31		43:40
	180	2:20						39		51:40
80 / 24.3	40	2:40								2:40
	70	2:40						14		22:00
	85	2:40						20		28:00
	100	2:40						26		34:00
	115	2:40						31		44:00
	130	2:40						37		50:00
	150	2:40						44		57:00
90 / 27.4	32	3:00								3:00
	60	3:00						14		22:20
	70	3:00						20		28:20
	80	3:00						25		33:20
	90	3:00						30		38:20
	100	3:00						34		47:20
	110	3:00						39		52:20
	120	3:00						43		56:20
	130	3:00						48		61:20
100 / 30.4	26	3:20								3:20
	50	3:20						14		22:40
	60	3:20						20		28:40
	70	3:20						26		34:40
	80	3:20						32		45:40
	90	3:20						38		51:40
	100	3:20						44		57:40
	110	3:20						49		62:40
	120	2:20				3		53		69:20
110 / 33.5	22	3:40								3:40
	40	3:40						12		21:00
	50	3:40						19		28:00
	60	3:40						26		35:00
	70	3:40						33		47:00
	80	2:40				1		40		55:00
	90	2:40				2		46		62:00
	100	2:40				5		51		70:00
	110	2:40				12		54		80:00

Table 7-6. Surface Decompression Table Using Oxygen (Continued).

Depth feet meters	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) breathing air at water stops (feet/meters) 60 18.2	50 15.2	40 12.1	30 9.1	Surface Interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompression time (min:sec)
120 36.5	18	4:00					TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		1-MINUTE 20 SECONDS ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	4:00
	30	4:00						9		18:20
	40	4:00						16		25:20
	50	4:00						24		33:20
	60	3:00				2		32		48:20
	70	3:00				4		39		57:20
	80	3:00				5		46		65:20
	90	3:00				7		51		72:20
	100	3:00				15		54		83:20
130 39.6	15	4:20								4:20
	30	4:20						12		21:40
	40	4:20						21		30:40
	50	3:20				3		29		41:40
	60	3:20				5		37		56:40
	70	3:20				7		45		66:40
	80	3:00			6	7		51		78:40
	90	3:00			10	12		56		92:40
140 42.6	13	4:40								4:40
	25	4:40						11		21:00
	30	4:40						15		25:00
	35	4:40						20		30:00
	40	3:40				2		24		36:00
	45	3:40				4		29		43:00
	50	3:40				6		33		54:00
	55	3:40				7		38		60:00
	60	3:40				8		43		66:00
	65	3:20			3	7		48		73:00
	70	3:00		2	7	7		51		82:00
150 45.7	11	5:00								5:00
	25	5:00						13		23:20
	30	5:00						18		28:20
	35	4:00				4		23		37:20
	40	3:40			3	6		27		46:20
	45	3:40			5	7		33		60:20
	50	3:20		2	5	8		38		68:20
	55	3:00	2	5	9	4		44		79:20
160 48.7	9	5:20								5:20
	20	5:20						11		21:40
	25	5:20						16		26:40
	30	4:20				2		21		33:40
	35	4:00			4	6		26		47:40
	40	3:40		3	5	8		32		63:40
	45	3:20	3	4	8	6		38		74:39

Table 7-6. Surface Decompression Table Using Oxygen (Continued).

Depth feet meters	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) breathing air at water stops (feet/meters) 60 18.2	50 15.2	40 12.1	30 9.1	Surface Interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompression time (min:sec)
170 51.8	7	5:40					TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		1-MINUTE 20 SECONDS ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	5:40
	20	5:40						13		24:00
	25	5:40						19		30:00
	30	4:20			3	5		23		42:00
	35	4:00		4	4	7		29		55:00
	40	3:40	4	4	8	6		36		74:00

Table 7-7. Surface Decompression Table Using Air.

Depth feet / meters	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) at water stops (feet/meters) 30 / 9.1	20 / 6.0	10 / 3.0	Surface Interval	Chamber stops (air) (min) (feet/meters) 20 / 6.0	10 / 3.0	Total decompression time (min:sec)
40 / 12.1	230	1:00			3	TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		7	15:20
	250	1:00			3			11	19:20
	270	1:00			3			15	23:20
	300	1:00			3			19	27:20
50 / 15.2	120	1:20			3			5	13:40
	140	1:20			3			10	18:40
	160	1:20			3			21	29:40
	180	1:20			3			29	37:40
	200	1:20			3			35	43:40
	220	1:20			3			40	48:40
	240	1:20			3			47	55:40
60 / 18.2	80	1:40			3			7	16:00
	100	1:40			3			14	23:00
	120	1:40			3			26	35:00
	140	1:40			3			39	48:00
	160	1:40			3			48	57:00
	180	1:40			3			56	65:00
	200	1:20		3			3	69	81:30
70 / 21.3	60	2:00			3			8	17:20
	70	2:00			3			14	23:20
	80	2:00			3			18	27:20
	90	2:00			3			23	32:20
	100	2:00			3			33	42:20
	110	1:40		3			3	41	53:50
	120	1:40		3			4	47	60:50
	130	1:40		3			6	52	67:50
	140	1:40		3			8	56	73:50
	150	1:40		3			9	61	79:50
	160	1:40		3			13	72	94:50
	170	1:40		3			19	79	107:50
80 / 24.3	50	2:20			3			10	19:40
	60	2:20			3			17	26:40
	70	2:20			3			23	32:40
	80	2:00		3			3	31	44:10
	90	2:00		3			7	39	56:10
	100	2:00		3			11	46	67:10
	110	2:00		3			13	53	76:10
	120	2:00		3			17	56	83:10
	130	2:00		3			19	63	92:10
	140	2:00		26			26	69	128:10
	150	2:00		32			32	77	148:10

Table 7-7. Surface Decompression Table Using Air (Continued).

Depth (feet) (meters)	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) at water stops (feet/meters) 30 / 9.1	20 / 6.0	10 / 3.0	Surface Interval	Chamber stops (air) (min) (feet/meters) 20 / 6.0	10 / 3.0	Total decompression time (min:sec)
90 27.4	40	2:40			3	TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		7	17:00
	50	2:40			3			18	28:00
	60	2:40			3			25	35:00
	70	2:20		3			7	30	47:30
	80	2:20		13			13	40	73:30
	90	2:20		18			18	48	91:30
	100	2:20		21			21	54	103:30
	110	2:20		24			24	61	116:30
	120	2:20		32			32	68	139:30
	130	2:00	5	36			36	74	158:30
100 30.4	40	3:00			3			15	25:20
	50	2:40		3			3	24	37:50
	60	2:40		3			9	28	47:50
	70	2:40		3			17	39	66:50
	80	2:40		23			23	48	101:50
	90	2:20	3	23			23	57	113:50
	100	2:20	7	23			23	66	126:50
	110	2:20	10	34			34	72	157:50
	120	2:20	12	41			41	78	179:50
110 33.5	30	3:20			3			7	17:40
	40	3:00		3			3	21	35:10
	50	3:00		3			8	26	45:10
	60	3:00		18			18	36	80:10
	70	2:40	1	23			23	48	103:10
	80	2:40	7	23			23	57	118:10
	90	2:40	12	30			30	64	144:10
	100	2:40	15	37			37	72	169:10

Table 7-7. Surface Decompression Table Using Air (Continued).

Depth (feet) (meters)	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) at water stops (feet/meters) 50 15.2	40 12.1	30 9.1	20 6.0	10 3.0	Surface Interval	Chamber stops (air) (min) (feet/meters) 20 6.0	10 3.0	Total decompression time (min:sec)
120 35.5	25	3:40					3	TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		6	17:00
	30	3:40					3			14	25:00
	40	3:20				3			5	25	41:30
	50	3:20				15			15	31	69:30
	60	3:00			2	22			22	45	99:30
	70	3:00			9	23			23	55	118:30
	80	3:00			15	27			27	63	140:30
	90	3:00			19	37			37	74	175:30
	100	3:00			23	45			45	80	201:30
130 39.6	25	4:00					3			10	21:20
	30	3:40				3			3	18	32:50
	40	3:40				10			10	25	53:50
	50	3:20			3	21			21	37	90:50
	60	3:20			9	23			23	52	115:50
	70	3:20			16	24			24	61	133:50
	80	3:00		3	19	35			35	72	172:50
	90	3:00		8	19	45			45	80	205:50
140 42.6	20	4:20					3			6	17:40
	25	4:00				3			3	14	29:10
	30	4:00				5			5	21	40:10
	40	3:40			2	16			16	26	69:10
	50	3:40			6	24			24	44	107:10
	60	3:40			16	23			23	56	127:10
	70	3:20		4	19	32			32	68	164:10
	80	3:20		10	23	41			41	79	203:10
150 45.7	20	4:20				3			3	7	22:30
	25	4:20				4			4	17	34:30
	30	4:20				8			8	24	49:30
	40	4:00			5	19			19	33	85:30
	50	4:00			12	23			23	51	118:30
	60	3:40		3	19	26			26	62	145:30
	70	3:40		11	19	39			39	75	192:30
	80	3:20	1	17	19	50			50	84	230:30
160 48.7	20	4:40				3			3	11	26:50
	25	4:40				7			7	20	43:50
	30	4:20			2	11			11	25	58:50
	40	4:20			7	23			23	39	101:50
	50	4:00		2	16	23			23	55	128:50
	60	4:00		9	19	33			33	69	172:50
	70	3:40	1	17	22	44			44	80	217:50

Table 7-7. Surface Decompression Table Using Air (Continued).

Depth (feet) (meters)	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) at water stops (feet/meters) 50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Surface Interval	Chamber stops (air) (min) (feet/meters) 20 / 6.0	10 / 3.0	Total decompression time (min:sec)
170 51.8	15	5:00				3		TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES	3	5	21:10
	20	5:00				4			4	15	33:10
	25	4:40			2	7			7	23	49:10
	30	4:40			4	13			13	26	66:10
	40	4:20		1	10	23			23	45	112:10
	50	4:20		5	18	23			23	61	140:10
	60	4:00	2	15	22	37			37	74	197:10
	70	4:00	8	17	19	51			51	86	242:10
180 54.8	15	5:20				3			3	6	22:30
	20	5:00			1	5			5	17	38:30
	25	5:00			3	10			10	24	57:30
	30	5:00			6	17			17	27	77:30
	40	4:40		3	14	23			23	50	123:30
	50	4:20	2	9	19	30			30	65	165:30
	60	4:20	5	16	19	44			44	81	219:30
190 57.9	15	5:40				4			4	7	25:50
	20	5:20			2	6			6	20	44:50
	25	5:20			5	11			11	25	62:50
	30	5:00		1	8	19			19	32	89:50
	40	5:00		8	14	23			23	55	133:50
	50	4:40	4	13	22	33			33	72	187:50
	60	4:40	10	17	19	50			50	84	240:50

CHAPTER 8

DIVING MEDICINE

8-1 INTRODUCTION

Training, planning, and equipment maintenance are the cornerstones of conducting safe diving operations. These, combined with experience, will ensure that the chance of an accident is minimized. However, the underwater environment is unforgiving and even minor mishaps can assume life-and-death proportions at depth. Also, conditions such as oxygen toxicity, decompression sickness, and arterial gas embolism may occur without warning and for no apparent reason. Therefore, it is absolutely necessary that all divers be familiar with the conditions described in this chapter as well as their treatment. The source of expertise in diving medicine is the Diving Medical Officer, but diving operations may have to be conducted without one being present. The Diving Medical Officer should be involved in predive planning and in training divers to deal with medical emergencies. Even if operators feel they know how to handle medical emergencies, a Diving Medical Officer should always be consulted in the event that things do not go according to plan.

Through training and experience, divers learn to handle a wide range of actual and potential emergency situations. They must be able to separate the important from the trivial, while recognizing that a seemingly minor symptom or event may foreshadow an emergency. They must be able to identify and react appropriately to the warning signals of various physiological disorders affecting themselves or other divers. They must have a working knowledge of the most effective methods for handling physical emergencies (e.g., diver entrapment, equipment malfunction), as well as a basic knowldege of the correct steps to take in treating medical emergencies. Most importantly, they must be able to handle an emergency while under emotional and physical stress.

When accidents occur, most of the time symptoms are obvious and treatment straightforward. However, experience has shown that divers must be able to judge the severity of symptoms, and evaluate a stricken diver's response to therapy. What is written in this chapter can only be a guideline for accomplishing this. Only thorough training by qualified personnel will give a diver the knowledge necessary to carry out the treatment protocols in this chapter. There are no easy, clearly identifiable rules to cover every situation. Training and the ability to analyze and react to unfamiliar situations are vital.

Following this introduction, Chapter Eight is divided into three sections. Section 8A covers diagnosis and treatment of diving disorders for which recompression therapy usually is not required. Section 8B covers the diagnosis of arterial gas embolism, other pulmonary overinflation syndromes (e.g., subcutaneous emphysema, pneumothorax, etc.), and decompression sickness. These conditions generally require recompression therapy. Section 8C covers actual recompression therapy and contains a section on treating omitted decompression. Section 8C does not address a particular type of treatment chamber, but the standard U.S. Navy double-lock aluminum chamber is considered as the most likely treatment platform. Certain chambers may have operational restrictions that prevent the exercise of all treatment options. As new chambers are introduced into the fleet, operational restrictions will be covered in Appendix D.

Many changes have occurred in this revision.

- The section on First Aid which includes Basic Cardiac Life Support (BCLS) has been moved to Appendix M. These procedures are constantly updated and this appendix should be kept as current as possible. Every diver shall maintain current American Heart Association (AHA) or equivalent certification in BCLS. This periodic refresher training on BCLS and first aid will not only keep the procedures in this annex up-to-date but will keep personnel sharp.

- A section on evaluating patients with decompression sickness has been included. This will help to ensure that urgency is driven by the patient's condition and that guidelines are established for evaluating treatment outcome.

- The initial treatment for arterial gas embolism has been changed. A large body of research plus operational experience has shown that immediate recompression to 60 feet will be adequate for treating the vast majority of cases. Deeper recompression is carried out after initial evaluation at 60 feet shows the patient is not responding or is deteriorating and deeper recompression is needed.

- A change has been made to O_2 breathing requirements for tenders on treatment tables.

- A new worksheet for evaluation of accident victims has been included in Appendix H. This worksheet should prove useful in ensuring that all pertinent information is collected regarding the cause and treatment outcome of accidents. Use of this worksheet is not mandatory; it is given as an aid.

It is important to realize that this chapter is a working document. While its procedures should be adhered to as closely as possible, any mistakes or discrepancies must be brought to the attention of NAVSEA immediately. There are instances where clear direction cannot be given; in these cases, the diving medical experts at NMRI or NEDU should be contacted for clarification.

Chapter 8 is designed as a reference for individuals trained in diving procedures. It is also directed to users with a wide range in medical expertise, from the fleet diver to the Diving Medical Officer. Certain treatment procedures require consultation with a Diving Medical Officer for safe and effective use. In preparing for any diving operation, it is mandatory that the dive team have a medical evacuation plan and know the location of the nearest or most accessible Diving Medical Officer.

SECTION 8A

DIVING DISORDERS NOT REQUIRING RECOMPRESSION THERAPY

8-2 BREATHING GAS DISORDERS

All members of the dive team must be constantly alert for signs and symptoms of such conditions as oxygen deficiency (hypoxia), carbon monoxide toxicity, carbon dioxide intoxication (hypercapnia), nitrogen narcosis, labored breathing (dyspnea) and oxygen toxicity. Full descriptions of the physiology of these disorders are given in Chapter 3.

8-2.1 Oxygen Deficiency. Oxygen deficiency or hypoxia, if not corrected promptly, leads to loss of judgement, unconsciousness, and can be fatal. The most common cause of hypoxia is interruption of the breathing gas supply. This situation is obvious and is treated by immediately reestablishing or shifting to an alternate gas supply.

Another cause of hypoxia is shifting to a gas with insufficient oxygen to the diver. Analysis of diving accidents in which this has occurred indicates that the first sign of trouble is an unresponsive diver and usually the immediate cause of the problem is not obvious. Always know the oxygen content of the diver's breathing gas! If a diver becomes unresponsive when mixed gas diving, hypoxia should be assumed until it is ruled out.

To begin immediate treatment for hypoxia:

(1) If the diver is in the water, shift to an alternate gas supply containing sufficient oxygen.

(2) If the diver is unconscious or incoherent, shift to 100-percent oxygen (if possible) when 40 fsw or shallower.

(3) Administer 100-percent oxygen at the surface.

(4) If the diver has lost consciousness or appears abnormal in any way, seek medical advice immediately.

Because the first sign of hypoxia may be unconsciousness, it may be difficult to differentiate hypoxia from arterial gas embolism in a diver who is ascending. However, recompression treatment for arterial gas embolism should also correct the hypoxia.

Treatment of hypoxia arising in specific operational environments is presented in Volume 2, for MK 15/16 dives and diving on closed-circuit oxygen rebreathers.

8-2.2 Carbon Monoxide (CO) Poisoning. Carbon monoxide poisoning from contamination of divers' air supply by exhaust gas fumes is rare. It will be treated the same way as low oxygen content of breathing gas. Divers suffering early symptoms of carbon monoxide (CO) toxicity (headache, nausea, vomiting) can be treated with 100-percent oxygen at the surface. Divers with neurological symptoms or who surface unconscious must be treated as if they had arterial gas embolism, since diagnosing CO toxicity requires laboratory tests that are time consuming and not readily available in the field. The associated high oxygen tension during the recompression treatment will also treat CO toxicity. In cases of suspected CO toxicity, the suspect breathing gas source should be isolated and gas samples forwarded for analysis as soon as possible.

8-2.3 Carbon Dioxide (CO_2) Intoxication. Carbon dioxide intoxication (hypercapnia) may occur with or without a deficiency of oxygen. Inadequate ventilation of open-circuit UBAs, controlled or skip-breathing, excessive breathing resistance, or excessive dead space in equipment (e.g., failure of mushroom valves in SCUBA mouthpiece) can cause buildup of carbon dioxide. In some closed-circuit and semi-closed-circuit underwater breathing apparatus, failure or expenditure of the carbon dioxide absorbent material will allow carbon dioxide to build up in the breathing gas. In cases where the oxygen partial pressure is above 0.5 atm, the shortness of breath usually associated with carbon dioxide intoxication may not be as severe as it would be at lower oxygen partial pressures. In these cases, especially when breathing hard because of physical exertion, the diver may have no warning of hypercapnia and may become confused and even slightly euphoric before losing consciousness.

Injury from hypercapnia is usually due to secondary effects such as drowning or other injury due to decreased mental function or unconsciousness. The high inspired CO_2 does in and of itself does not usually cause permanent injury. Because the first sign of hypercapnia may be unconsciousness and it may not be readily apparent whether the cause is hypoxia or hypercapnia, rule out hypoxia first. First correct any hypoxia, then take action to correct the hypercapnia.

To treat carbon dioxide intoxication, lower the inspired carbon dioxide level by (1) increasing helmet ventilation, (2) decreasing the level of exertion, (3) shifting to an alternate breathing apparatus, and/or (4) aborting the dive if defective equipment is the cause. Divers surfacing unconscious should be treated as if they had arterial gas embolism.

Treatment of hypercapnia specific operational environments is presented in Volume 2 for MK 15/16 diving operations and diving involving closed-circuit oxygen rebreathers.

8-2.4 Oxygen Toxicity. Oxygen toxicity affects the lungs (Pulmonary Oxygen Toxicity) or the central nervous system (CNS Oxygen Toxicity). Pulmonary oxygen toxicity may occur during long oxygen exposures such as recompression treatments, special 100-percent oxygen UBA operations, and saturation dives. Pulmonary oxygen toxicity is covered in Paragraph 8-15.4.1.

During in-water diving operations, the most common and most serious form of oxygen toxicity that occurs involves the central nervous system (CNS). The symptom of CNS oxygen toxicity that has the most serious consequence is the oxygen convulsion. The convulsion in and of itself is not harmful and there will be no residual effects provided injury or drowning can be prevented.

CNS oxygen toxicity is usually not encountered unless the partial pressure of oxygen approaches or exceeds 1.6 atm. However, oxygen convulsion may be encountered at oxygen partial pressure as low as 1.3 ata. Signs and symptoms of CNS oxygen toxicity include the following.

- **Vision -** any abnormality, such as tunnel vision (a contraction of the normal field of vision, i.e., tunnel vision)
- **Ears -** any abnormal sounds, especially ringing or roaring
- **Nausea -** may be intermittent
- **Twitching -** usually first appears in the lips or other facial muscles. This is the most frequent and clearest symptom.
- **Irritability -** any change in behavior, including anxiety or confusion
- **Dizziness**
- **Tingling -** of the extremities

These symptoms may occur singly or together. They occur in no particular order and there is no one symptom which could be considered more serious than another, or which is a better warning of an impending convulsion. ***The first sign of CNS oxygen toxicity may be a convulsion which occurs with little or no warning.***

If a tethered diver thinks he has symptoms of oxygen toxicity, the diver should inform the Diving Supervisor who should take action to lower the oxygen partial pressure. Such actions include:

(1) Decreasing diver depth 10 feet.

(2) Discontinuing 100-percent oxygen and venting the UBA with a gas of lower oxygen content with a partial pressure less than 1.0 atm.

Free swimming divers on 100-percent oxygen UBA should alert their diving partner and surface (if possible).

If a diver convulses, the UBA should be ventilated immediately with a gas of lower oxygen content, if possible. If depth control is possible and gas supply is secure (helmet or full face mask), the diver's depth should be kept constant until the convulsion subsides. If an ascent must take place, it should be done as slowly as possible. If a diver surfaces unconscious because of an oxygen convulsion or to avoid drowning, the diver must be treated as if suffering from arterial gas embolism. Convulsing divers in the recompression chamber should be protected from physical harm. When the convulsion subsides, the diver should be kept with head back and chin up to ensure an adequate airway until consciousness is regained. Forcing the mouth open to insert a bite block is unnecessary. CNS oxygen toxicity occurring during recompression therapy is discussed fully in Paragraph 8-15.4.1.

Treatment of CNS oxygen toxicity in specific operational environments is presented in Volume 2 for surface-supplied HeO_2 diving, MK 15/16 diving operations and 100-percent oxygen rebreather dives.

8-2.5 Nitrogen Narcosis. The only effective way to counteract the narcotic effect of nitrogen is to lower the nitrogen partial pressure. Specifically:

(1) Diver should ascend or be brought to a shallower depth.

(2) If mental acuity is not restored, the dive must be aborted.

8-2.6 Shortness of Breath (Dyspnea). The increased density of the breathing gas at depth, combined with physical exertion, may lead to shortness of breath that may become severe and cause panic in some divers.

Dyspnea is usually associated with carbon dioxide buildup in the body, but may occur without it. When dyspnea occurs, the diver must rest until the shortness of breath subsides. This may take several minutes. If dyspnea does not subside with rest, or if it returns with even slight exertion, it may be due to carbon dioxide buildup. In open-circuit UBAs (i.e., MK 12), ventilation rates should be checked to make sure they are adequate; the helmet should be ventilated if necessary. Adequate ventilation rates are at least four acfm for moderate work and six acfm for very hard work. Ventilation should not drop below one acfm, even at rest.

In demand systems, excessive dead space from a damaged oral-nasal may be the cause. In closed or semiclosed UBAs, the CO_2 absorbent canister may be spent. If these causes are likely, the dive must be aborted to correct them.

8-2.7 Hyperventilation. Hyperventilation may result from rapid breathing due to malfunction in breathing apparatus or, occasionally, apprehension. It results in an excessive lowering of carbon dioxide levels in blood. This, in turn, may lead to a biochemical imbalance which gives rise to dizziness and twitching or tingling of the extremities which may be mistaken for convulsions. Usually, this twitching is also accompanied by some degree of spasm of the small muscles of the hands and feet which allows a sure diagnosis to be made. Treatment is to slow down the breathing rate by direction and reassurance which allows the condition to correct itself.

8-3 BAROTRAUMA

Barotrauma, or damage to body tissues from the mechanical effects of pressure, results when pressure differentials between body cavities and the hydrostatic pressure surrounding the body, or between the body and the diving equipment, are not equalized properly. Barotrauma most frequently occurs during descent, but may also occur during ascent.

8-3.1 Squeeze. Squeeze during descent occurs when gas in a cavity is compressed. The types of squeeze most frequently encountered in diving are:

- Middle-ear squeeze - the most common form of barotrauma, caused by a blocked eustachian tube. This may result in eardrum rupture or bleeding into the middle ear space, sometimes causing dizziness.

- External-ear squeeze - caused by a hood or other piece of equipment covering the external ear passage. This may also result in eardrum rupture which may result in dizziness.

- Sinus squeeze - caused by blocked passages that vent the sinuses to the upper respiratory air passages.

- Lung (thoracic) squeeze - an extremely rare condition, caused by compression of air in the lungs to a volume less than residual volume. This could happen in an extremely deep breathhold (free) dive or as a part of a whole body squeeze.

- Whole body squeeze - caused by a failure of the air supply in a dry suit to balance water pressure. This could be precipitated by a sudden or unexpected increase in depth, by the malfunction or maladjustment of supply and exhaust valves, or by the absence or failure of the safety non-return valve.

- Face mask squeeze - caused by a failure to equalize air in the mask by nasal exhalation, or, with full face mask, by malfunction of the air supply or the valving.

- Suit squeeze - caused by a pocket of air in a dry suit that becomes trapped under a fold or fitting and pinches the skin in the fold area.

To treat squeeze during descent:

(1) Stop descent.

(2) If efforts to equalize pressure fail, ascend a few feet.

(3) If further efforts to equalize pressure fail, abort the dive.

(4) If the diver reports dizziness, ventilate the diver, abort the dive, and evaluate the need to send down the standby diver to assist.

(5) Report the squeeze to the medical personnel trained in Diving Medicine for appropriate treatment.

Reverse squeeze occurs when gas trapped in a cavity cannot escape as it expands during ascent.

To treat reverse squeeze of the middle ear or sinus during ascent:

(1) Stop ascent and, if clearing does not occur spontaneously, descend two to four feet.

(2) Ascend slowly and in stages to allow additional time for equalization.

(3) Evaluate the need to send down the standby diver to assist if difficulty persists. Vertigo may develop.

(4) Upon surfacing, report the problem to the medical personnnel trained in Diving Medicine for appropriate treatment.

Sinus and ear squeeze are best prevented by taking a nasal decongestant about one hour before diving if mild congestion is present, or by not diving in cases of severe congestion. If decongestants must be used, check with medical personnel trained in Diving Medicine to obtain medication that will not cause drowsiness and possibly add to symptoms caused by the narcotic effect of nitrogen.

8-3.2 Gastrointestinal Distention as a Result of Gas Expansion. Divers may occasionally experience abdominal pain during ascent because of gas expansion in the stomach or intestines. This condition results either from the generation of gas in the intestines during a dive, or more commonly from the swallowing of air (aerophagia). These pockets of gas will usually work their way out of the system through the mouth or anus. If not, distention will occur. If the pain begins to pass the stage of mild discomfort, ascent should be halted and the diver should descend slightly until the pain is relieved. The diver should then attempt to gently burp or release the gas anally. Overzealous attempts to belch should be avoided as they may result in swallowing more air.

Most intestinal gas expansion can be avoided by two simple precautions: (1) do not dive with an upset stomach or bowel, (2) avoid eating foods that are likely to produce intestinal gas, and (3) minimize swallowing air during a dive by avoiding a steep head-down angle during descent.

8-3.3 Ear Barotrauma. Simple ear squeeze is discussed in Paragraph 8-3.1. More serious forms are rupture of the ear membranes, the eardrum or round or oval window.

8-3.3.1 Eardrum Rupture. Ear squeeze may result in eardrum rupture. The diver will experience intense pain as the eardrum stretches. When rupture occurs, this pain will diminish rapidly. If eardrum rupture is suspected, the dive must be aborted. Vertigo and/or nausea may occur if water enters the middle ear. All cases of suspected eardrum rupture should be referred to a Diving Medical Officer. Antibiotics and pain medication taken orally may be required. ***Medications should never be administered directly into the canal of a ruptured eardrum unless done in direct consultation with an ear, nose, and throat medical specialist.***

8-3.3.2 Round or Oval Window Rupture. The round window and oval window are membranes which separate fluid in the inner ear with the middle ear. Symptoms of round or oval window rupture of the ear may become evident on the bottom or after the diver reaches the surface. Usually, the diver will have had difficulty clearing his ears during descent but symptoms may arise for no apparent reason. The diver may have ringing or roaring in the affected ear, hearing loss, vertigo, disorientation, or unsteadiness. These symptoms may occur singly or in combination. Cases have been reported where the only symptom has been an isolated hearing loss. If a diver surfaces with any of these symptoms and relates difficulty clearing his ears on descent, round or oval window rupture should be suspected. Treatment includes head elevation, bed rest, and immediate consultation with appropriate medical specialists. See Paragraph 3-6.10 for a complete discussion.

Any or all of the symptoms of round or oval window rupture may follow dives with depth/time profiles which could give rise to inner ear decompression sickness or arterial gas embolism for which recompression is the only appropriate treatment. Differentiating between these causes may be impossible, and experimental and anecdotal evidence now exists to show recompression will have no adverse effect on round or oval window rupture if simple precautions are taken. If the possibility exists that post-dive vertigo, deafness, and tinnitus may be due to decompression sickness, recompression therapy should be instituted. If round or oval window rupture is the true cause of symptoms, recompression will usually not provide relief, and no CNS symptoms other than those which refer to the inner ear will be present. During decompression from treatment depth, the diver with suspected round or oval window rupture should not be exposed to excessive positive or negative pressure when breathing oxygen on a Built-in Breathing System (BIBS) mask. The diver should be kept in an upright sitting position. After surfacing from treatment, bed rest, head elevation, and hospitalization are indicated until an audiological workup can be completed by medical specialists.

8-3.3.3 Middle Ear Oxygen Absorption Syndrome. Middle ear oxygen absorption syndrome refers to the negative pressure which may develop in the middle ear following a long oxygen dive. Gas with a very high percentage of oxygen enters the middle ear cavity during the course of an oxygen dive. Following the dive, the oxygen is slowly absorbed by the tissues of the middle ear. If the eustachian tube does not open spontaneously, a negative pressure relative to ambient may result in the middle ear cavity. Symptoms are often noted the morning after a long oxygen dive. Middle ear oxygen absorption syndrome is difficult to avoid but usually does not pose a significant problem because symptoms are generally minor and easily eliminated. There may also be fluid (serous otitis media) present in the middle ear as a result of the differential pressure.

The diver may notice mild discomfort and hearing loss in one or both ears. There may also be a sense of pressure and a moist, cracking sensation as a result of fluid in the middle ear.

Equalizing the pressure in the middle ear using a normal Valsalva maneuver or the diver's procedure of choice (e.g., swallowing, yawning) will usually relieve the symptoms. Discomfort and hearing loss resolve quickly, but the middle ear fluid is absorbed more slowly. If symptoms persist, a Diving Medical Technician or Diving Medical Officer shall be consulted.

8-4 DISORDERS OF HIGHER FUNCTION AND CONSCIOUSNESS

Divers may experience sensations while at depth which they would describe as dizziness or in some situations may lose consciousness. The causes of these conditions are not always obvious and surfacing the diver may not be possible because of decompression obligations. Therefore, it is important to know what the potential causes of these disorders are in order to decide the possibility of injury to the diver.

8-4.1 Lightheaded or Dizzy Diver on the Bottom. Dizziness is a common term used to describe a number of feelings, including lightheadedness, unsteadiness, vertigo (a sense of spinning), or the feeling that one might pass out. There are a number of potential causes of dizziness in surface-supplied diving including carbon dioxide accumulation, hypoxia, a gas supply contaminated with toxic gases such as methylchloroform, and trauma to the inner ear caused by difficult clearing of the ear. At the low levels of oxygen specified for surface-supplied diving, oxygen toxicity is an unlikely cause unless the wrong gas has been supplied to the diver.

The first step to take is to have the diver stop work and ventilate the rig while topside checks the oxygen content of the supply gas. These actions should eliminate carbon dioxide and hypoxia as causes. If a temporary improvement in symptoms occurs after ventilation, followed by a return of the original problem then defective CO_2 absorbent cannister (Paragraph 8-2.6) or hyperventilation (Paragraph 8-2.7) should be suspected. The diver should stop work, ventilate his UBA and abort the dive. A contaminated gas supply may be the culprit and the suspected gas should be isolated for analysis. However, there is a wide variety of ordinary medical conditions that may also lead to dizziness while the diver is on the bottom.

8-4.2 Vertigo. The sensation of the diver spinning or the environment spinning is called vertigo. Vertigo may be due to cold water stimulation of the intact ear, eardrum rupture, round or oval window rupture, changes in middle ear pressure, arterial gas embolism, or decompression sickness. Transient vertigo usually occurs during descent but may occur during ascent. Trassient vertigo due to pressure differences between the middle ears usually disappears after the diver has reached the bottom or stops travel, and is usually related to a diver having difficulty "clearing his ears". It would be unusual for alternobaric vertigo to occur after the diver had been on the bottom for more than a few minutes. Vertigo may also occur when passing through thermoclines (caloric vertigo). Travel should be halted until the vertigo resolves. Some divers may become severely disoriented and require assistance. When the vertigo subsides, the dive may be continued. Persistent vertigo, such as that due to round window rupture, will require that the dive be aborted and the diver examined as soon as possible by a Diving Medical Officer. Vertigo due to round window rupture may be indistinguishable from symptoms of arterial gas embolism or decompression sickness, and recompression should be instituted if the cause cannot be determined (see Paragraph 8-3.3.2).

8-4.3 Unconscious Diver on the Bottom. An unconscious diver on the bottom constitutes a serious emergency. Only general guidance can be given here. Management decisions must be made on site, taking into account all known factors. The advice of a Diving Medical Officer shall be obtained at the earliest possible moment.

If the diver becomes unconscious on the bottom, first take steps to ensure that the breathing medium is adequate and that the diver is breathing. Check the status of any other divers. If there is any reason to suspect gas contamination, shift to the standby supply. Have the dive partner or standby diver ventilate the afflicted diver to remove accumulated carbon dioxide in the helmet and ensure the correct oxygen concentration. When ventilation is complete, have the dive partner or standby diver ascertain whether the diver is breathing. In the MK 21, the presence or absence of breath sounds will be audible over the intercom. If the diver appears not to be breathing, the dive partner/standby diver should attempt to reposition the diver's head to open the airway. Airway obstruction will be the most common reason why an unconscious diver fails to breathe.

If the diver regains consciousness after the maneuvers outlined above, allow a short period for stabilization and then abort the dive. If the diver remains unresponsive, have the dive partner or standby diver move the afflicted diver to the stage. If the diver is breathing, this action need not be rushed. If the diver appears not to be breathing, further attempts to open the airway should be made while moving the diver rapidly to the stage. Once the diver is on the stage, observe again briefly for the return of consciousness. If consciousness returns, allow a period for stabilization, then begin decompression. If consciousness does not return, bring the diver to the first decompression stop at a rate of 30 fsw/min (or to the surface at a rate of 60 fsw/min if the diver is in a no-decompression status). Decompress the diver using surface decompression procedures.

If the diver remains unconscious at the first decompression stop and breathing cannot be detected in spite of repeated attempts to position the head and open the airway, an extreme emergency exists. One must weigh the risk of catastrophic, even fatal, decompression sickness if the diver is brought to the surface, versus the risk of asphyxiation if the diver remains in the water. As a general rule, if there is any doubt about the diver's breathing status, assume he is breathing and continue decompression. If it is ***absolutely*** certain that the diver is not breathing, leave the unaffected diver at his first decompression stop to complete decompression, and surface the affected diver at 60 fsw/minute, deploying the standby diver as required. Recompress immediately and treat for omitted decompression.

8-5 NEAR-DROWNING

8-5.1 Causes and Prevention. A swimmer can fall victim to drowning because of overexertion, panic, inability to cope with rough water, exhaustion, or the effects of cold water or heat loss. These same factors can affect a diver, but if the diver is properly equipped, trained, and monitored by a partner or tender, drowning should be a remote possibility.

Drowning in a hard hat diving rig (MK 12) is rare. It can happen if the helmet is not properly secured and comes off, or if the diver is trapped in a head-down position with a water leak in the helmet. Normally, as long as the diver is in an upright position and has a supply of air, water can be kept out of the helmet no matter what the condition of the suit.

Divers wearing lightweight or SCUBA gear can drown if they lose or ditch their mask or mouthpiece, run out of air, or inhale even small quantities of water. This could be the direct result of failure of the air supply, or panic in a hazardous situation. The SCUBA diver, because of direct exposure to the environment, can be affected by the same conditions that may cause a swimmer to drown.

The prevention of drowning is best ensured by the establishment of and thorough training in safe diving practices coupled with the careful selection of diving personnel. A trained diver should not easily fall victim to drowning. However, overconfidence can give a feeling of false security that might lead a diver to take dangerous risks.

8-5.2 Treatment. The treatment of near-drowning falls into two phases: (1) restore breathing and heartbeat, and (2) call for assistance from qualified medical personnel. Regardless of the severity of a near-drowning case, hospitalize all victims as quickly as possible. Pulmonary edema (accumulation of fluids in the lungs), pneumonia, and other complications may occur many hours after the incident. Therefore, proper medical observation is essential. Subsequent to resuscitation, while awaiting transportation to medical facilities, keep the patient warm and rested. Give 100-percent oxygen by mask if any symptoms persist.

8-5.2.1 Rescue Breathing. Initial treatment of the near-drowning victim consists of rescue breathing using the mouth-to-mouth or mouth-to-nose technique. Rescue breathing should be started as soon as possible, even before the victim is moved out of the water. Proper techniques are given in Appendix M.

If neck injury is suspected, however, the victim's neck should be supported in a neutral position (without flexion or extension), and the victim should be floated supine onto a horizontal back support before being removed from the water. If the victim must be turned, the head, neck, chest, and body should be aligned, supported, and turned as a unit to the horizontal supine position. If artificial respiration is required, maximal head-tilt should not be used. Rescue breathing should be provided with the head maintained in a neutral position, i.e., jaw-thrust without head-tilt, or chin-lift without head-tilt, should be used.

8-5.2.2 Foreign Matter in the Airway. The need for clearing the lower airway of aspirated water has not been proved scientifically, although there are anecdotal reports of clinical response to a Heimlich Maneuver. At most, only a modest amount of water is aspirated by the majority of both freshwater and seawater drowning victims, and freshwater is rapidly absorbed from the lungs into the circulation. Furthermore, 10 to 12 percent of victims do not aspirate at all due to laryngospasm or breath-holding. An attempt to remove water from the breathing passages by any means other than suction is usually unnecessary and dangerous because it could eject gastric contents and cause aspiration.

Because the risk-benefit ratio of a Heimlich Maneuver in this setting is unknown, the only time it should be used is when the rescuer suspects that foreign matter is obstructing the airway or if the victim does not respond appropriately to mouth-to-mouth ventilation. Then, if necessary, CPR should be reinstituted after the Heimlich Maneuver has been applied. The Heimlich Maneuver is performed on the near-drowning victim in the same way as for the treatment of foreign-body airway obstruction (unconscious supine) except that in near-drowning, the victim's head should be turned sideways. Details are found in Appendix M.

8-5.2.3 Chest Compressions. In-water chest compressions are probably ineffective so the individual should be removed from the water as fast as possible.

On removal from the water, the victim must be assessed immediately for adequacy of circulation. The pulse may be difficult to detect in a near-drowning victim because of peripheral vasoconstriction and a low cardiac output. If a pulse cannot be felt, CPR should be started at once.

8-5.2.4 Definitive Advanced Life-Support Care. There should be no delay in moving the victim of near-drowning to a life-support unit where advanced life support is provided. Every near-drowning victim, even one who requires only minimal resuscitation and regains consciousness at the scene, should be transferred to a medical facility for follow-up care. It is imperative that life-support measures be continued en route and that oxygen be administered if it is available in the transport vehicle.

Successful resuscitation with full neurological recovery has occurred in near-drowning victims with prolonged submersion in cold water. An absolute time limit beyond which resuscitation is not indicated has not been established. Since it is often difficult for rescuers to obtain an accurate time of submersion, attempts at resuscitation should be initiated by rescuers at the scene unless there is obvious physical evidence of death (such as severe trauma putrefaction). The victim should be transported with continued CPR to an advanced life-support facility where a physician can decide whether to continue resuscitation.

8-6 THERMAL STRESS

Thermal stress occurs when the difference between the water and body temperature is large enough such that the body will gain heat (hyperthermia) or lose heat (hypothermia). It both conditions mild exposures will lead mainly to discomfort, but one must always be aware of the signs and symptoms of more severe stress. In these cases, either proper protective equipment should be worn, or exposure limited.

8-6.1 Hyperthermia. The signs and symptoms of hyperthermia are covered in Chapter Three. As a general guideline, any diving operations conducted in water warmer than 82°F and/or air temperatures above 90°F, should have personnel on alert for possible signs of hyperthermia (see Table 3-2, Chapter Three). If possible, personnel should be acclimatized as outlined in Chapter Three, and plenty of fluids should be available to avoid dehydration. Experience has shown that acclimatized individuals can perform light to moderate work in 94°F for several hours without suffering severe hyperthermia while wearing cotton coverallls or a dry suit outergarment. If a dry suit (or other impermeable garment) must be worn in warm water, the undergarment thickness should be minimized, and the absolute minimum inflation used. When diving in water hotter than 95°F specialized cooling garments may be necessary. NAVSEA 00C should be consulted if such garments are required.

Experienced divers will be able to pace themselves to avoid heat stress. Discomfort and hyperventilation during dives (e.g., excessive air consumption or other symptoms listed in Table 3-2) should be reason to limit exposures. Development of reductions in ability to think clearly, erratic swimming or working patterns, fatigue, nausea or muscle cramps, are less severe signs that warrant aborting a dive. However, even with proper preparation, hyperthermia may occur and divers should be familiar with the signs and symptoms as well as treatment.

Prolonged core temperatures greater than 102°F can produce muscle weakness or tremors, muscle cramps, nausea, vomiting or cardiovascular collapse. Appearance of any of these signs or symptoms must be treated as a medical emergency; cooling and hydration treatments must be started immediately.

All cases of hyperthermia must include cooling of the diver to reduce core temperature. In mild cases, removing the diver to a shaded or cool area may be sufficient. In more severe cases, cooling can be achieved by having the diver lie down and applying a fine mist of 75-85°F water to his skin, and fanning the patient. Cold water or ice should never be used on the whole body since this will cause vasoconstriction which decreases blood flow to the skin, which may slow the process of lowering core temperature. Ice packs to the neck, arm pit or groin may be used.

Conscious patients should be given non-alcoholic beverages to drink, one quart every hour for each two pound weight loss. Adequate rehydration is achieved when the patient has urine that is pale to clear. It may take 2-4 hours for a severely dehydrated diver to produce urine. Failure to urinate after four hours of fluid replacement, may indicate kidney damage.

Unconscious patients should be rehydrated via intravenous fluid replacement. Pulmonary edema can occur if too much fluid is infused early in treatment, when peripheral vasodilation is present. Subsequent cooling of the skin will cause vasoconstriction, forcing more fluid into the thoracic vessels.

All severe cases of hyperthermia should be suspected of having muscle, liver or kidney damage; hospitalization is warranted. Divers who have suffered a severe case of hyperthermia may be more sensitive to subsequent heat stress. Caution should be excercised before allowing these persons to resume warm water diving.

8-6.2 Hypothermia. Immersion hypothermia is a potential hazard whenever diving operations take place in cool to cold waters. A diver's response to immersion in cold water depends on the degree of thermal protection worn and water temperature. An unprotected individual suddenly immersed in very cold water will experience pain, may have difficulty controlling his respirations, and will begin to lose muscle strength and coordination even before core temperature begins to drop. If some form of thermal protection is worn but it is inadequate, these initial responses may be somewhat blunted so that less discomfort is experienced but the end result will be the same, core temperature will fall.

The signs and symptoms of falling core temperature are given in Table 3-1 (Chapter Three). Responses to falling core temperature are individual. Eventually, however, mental confusion and irrational actions or responses will occur resulting in a diver who is incoherent, cannot assist himself out of the water and cannot handle gear, or walk normally. No matter what the core temperature, individuals in this state are seriously hypothermic and will require immediate assistance and rewarming.

When cooling reaches a certain point shivering begins. Shivering is involuntary muscle contractions which generate heat and can prevent core temperature from falling up to a point, falling to a limited extent. Depending on the type of thermal protection (or lack of protection) worn by the diver, shivering may eventually lead to conditions conditions which result in increased heat loss from the skin and further drops in core temperature. As cooling continues, shivering will cease as muscle energy stores are depleted. This will increase the rate of core temperature drop, resulting in collapse, unconsciousness, dangerous rhythms of the heart and depressed respiration.

Cold water immersion may also cause excessive urination, severely dehydrating the diver. This in turn reduces performance and may increase the risk of developing decompression sickness. A diver who is dehydrated may appear normal in the water. However, exiting the water combined with warming of the skin may cause pooling of the blood in the extremities leading to fainting. This means that divers who have been in cold water for any period of time and who appear cold should be assisted from the water and sit or lie down and take fluids until they are sure they can stand without problems.

Hypothermia is prevented by selecting the appropriate diving suit (wet suit, dry suit, hot water suit) considering both the water temperature and the planned duration of the dive. Less insulation will improve the diver's dexterity and ability to swim, but will also contribute to a greater loss of heat and increase the risk of hypothermia. Adequate thermal support for divers is a necessity if operations are to proceed safely.

The treatment of hypothermia consists of rewarming the victim. In mild cases, when the diver is only chilled, treatment is still important if diving operations are to continue. Hypothermia severe enough to cause confusion or unconsciousness is a medical emergency and rewarming must be started immediately.

The quickest and most efficient way to rewarm the diver is with hot water, either in a bath or directed under the diver's suit. Rapid rewarming, if necessary, is best accomplished using water 100-110°F (38-44°C). Using water hotter than 113°F (45°C) may burn the diver's skin. If no hot water is available, the next alternative is to dry the diver and provide warm clothes, a sleeping bag or blankets and a warm room. Caution should be used with chemical hot packs or electric pads or blankets which can scald or burn the skin. A diver in stable condition who is shivering under dry insulation (blankets, sleeping bag) will rewarm safely.

Hot showers are useful in rewarming chilled divers who are conscious, able to stand without assistance, and who have adequate hydration. Wet suits do not have to be removed for a hot shower to be effective. However, a tight fitting wet suit may have contributed to the problem by constricting peripheal circulation, in these cases loosen or remove the garment. Since the warm water will cause peripheral vasodilation, individuals who are dehydrated may faint in a shower, so sitting on a chair or cot in the shower or rewarming in a bathtub is a safer method of rewarming.

A diver who has become chilled must be brought out of the water and his body temperature restored by rewarming techniques before serious complications arise. If dehydrated, body fluids must be replaced with warm beverages free of caffeine (caffeine may cause additional urination and further dehydration). The seriously hypothermic diver should be handled gently, not allowed to walk, and should be transported horizontally to prevent dangerous rhythms of the heart. Intravenous (IV) fluid rehydration should be instituted. In profound hypothermia, the victim can even appear to be dead due to undetectable pulse and respirations, dilated pupils, and an ashen-grey color of the skin.

In such a case, resuscitation and rewarming must be started immediately, even though the diver has not been breathing for some time. Resuscitation should be continued until the victim has been rewarmed. The victim should not be considered dead until he is completely rewarmed and continues to be unresponsive to properly applied resuscitation efforts.

A diver should be rewarmed completely before attempting a repetitive dive in cold water. Studies have shown that people suffering from heat loss invariably report feeling warm soon after they stop shivering, although rewarming may be less than complete. A simple indicator that rewarming is complete, after moderate exposure, is the onset of sweating. In repetitive diving with cold exposure, the operation should be planned so that the diver is rewarmed to the point of sweating before diving again. If cold water exposures are severe and if more than a 30 minute duration, then consideration should be given to requiring an overnight rest between exposures. The Diving Medical Officer should be consulted when there is doubt as to exposure severity. The diver must also have sufficient noncaffeine beverages to replace the excessive body fluid loss from cold water induced urination.

Hypothermia may also result from breathing cold helium-oxygen gases even if his skin is warm. This condition is prevented by adhering to minimum inspired gas temperature limits as outlined in Paragraph 12-6.2.2.

8-7 OPERATIONAL HAZARDS

Most physical emergency situations, such as umbilical fouling, entrapment, and equipment failure, have been mentioned in previous chapters. Those with direct medical implications will be recounted briefly in this section, with elaboration when necessary for a clear understanding of the problem and the solution.

8-7.1 Blowup. Blowup occurs when a diver becomes overbuoyant and is carried upward in an uncontrolled ascent. As the diver rises, the expanding gas in the life vest, buoyancy compensator, or dry suit progressively increases the rate of ascent. If the diver is unable to vent the expanding gas volume, he will be unable to stop the ascent. Blowup can lead to serious problems, including arterial gas embolism, decompression sickness, and physical injury from collision with surface objects. Even if no injury occurs, required decompression may be omitted. Should a dry suit rupture from the high internal pressure, the diver could fall back to depth if not properly tended. Serious squeeze or drowning could result.

Modern diving equipment is designed to minimize the chance of blowup. Buoyancy compensators and variable volume dry suits will usually have exhaust valves capable of venting gas faster than it can expand during ascent. The MK

12 outer garment provides a physical barrier to prevent overinflation of the dry suit. When wearing variable-volume dry suits, blowup may occur if the individual has not been trained properly in adjusting suit volume. Also, blowup may occur if a diver inadvertently activates the life vest at depth. A diver should be particularly wary of the possibilities of blowup when executing any maneuver that requires an increase in buoyancy, particularly if trying to work free from a muddy bottom or similar situation where the diver is likely to break free suddenly.

Prevention of blowup is essential. Prevention includes proper training in establishing dry suit volumes and in the use of buoyancy compensators. In addition, proper suit or buoyancy compensator exhaust valve function should be checked at intervals throughout the dive, especially in conditions where silt or sand may clog exhaust valves.

If caught in a blowup, the diver must exhale continuously to avoid arterial gas embolism. When ascending, the diver should vent enough air to prevent rupture of the suit at the surface while maintaining positive buoyancy. Treatment of blowup is found in Paragraph 8-13.2 for air diving and in Volume 2, Paragraph 11-4.10 for deep helium diving.

8-7.2 Otitis Externa. Otitis externa (swimmer's ear) is an infection of the ear canal caused by repeated immersion. The water in which the dive is being performed does not have to be contaminated with bacteria for otitis externa to occur. Repeated immersion breaks down the skin lining the ear canal; bacteria normally present in the canal multiply, causing infection. The first symptom of otitis externa is an itching and/or wet feeling in the affected ear. This feeling will progress to local pain as the external ear canal becomes swollen and inflamed. Local lymph nodes (glands) may enlarge making jaw movement painful. Fever may occur in severe cases. Once otitis externa develops, the diver should discontinue diving and be examined and treated by a Diving Medical Officer. Unless preventive measures are taken, this condition is very likely to occur during diving operations, causing unnecessary discomfort and loss of time. At a minimum, external ear prophylaxis, a technique to prevent swimmer's ear, should be done each morning, after each wet dive, and each evening during diving operations. External ear prophylaxis is accomplished using a two-percent acetic acid in aluminum acetate (e.g., Otic Domeboro) solution. The head is tilted to one side and the external ear canal gently filled with the solution, which must remain in the canal for five minutes. The head is then tilted to the other side, the solution allowed to run out, and the procedure repeated for the other ear. The five-minute duration must be timed with a watch. ***If the solution does not remain in the ear a full five minutes, the effectiveness of the procedure is greatly reduced.***

During prolonged diving operations, the external ear canal may become occluded with wax (cerumen). When this happens, external ear prophylaxis is ineffective and the occurrence of otitis externa will become more likely. Periodic examination of the external ear canal with an otoscope can be used to detect the presence of wax. If the eardrum cannot be seen during examination, the ear canal should be flushed gently with water to remove the excess cerumen. Dilute hydrogen peroxide or sodium bicarbonate solutions may be more effective. Never use swabs or other instruments to remove cerumen; this is to be done only by trained medical personnel. Otitis externa is a particular problem in saturation diving if prophylactic measures are not adhered to (see Paragraph 12-18.2).

8-7.3 Underwater Trauma. Underwater trauma is different from trauma that occurs at the surface because it may be complicated by the loss of the diver's gas supply and by the diver's decompression obligation. If possible, injured divers should be surfaced immediately and treated appropriately. If an injured diver is trapped, the first priority is to ensure sufficient breathing gas is available, then to stabilize the injury. At that point, a decision must be made as to whether surfacing is possible. If the decompression obligation is great, the injury will have to be stabilized until sufficient decompression can be accomplished. If an injured diver must be surfaced with missed decompression, the diver must be treated as soon as possible, realizing that the possible injury from decompression sickness may be as severe or more severe than that from the other injuries.

8-7.4 Injuries Caused by Marine Life.
These types of injuries will depend on the geographical location and local marine plants and animals. In planning diving operations, potential marine hazards should be identified and local experts consulted on treatment experience and antisera availability for the treatment of envenomation. Treatment advice should be formalized into procedures and filed in Appendix G of this manual for ready reference during operations. Suitable references on the subject are listed in Appendix G.

8-7.5 Communicable Diseases and Sanitization. The use of unsanitized diving equipment presents a health hazard which can be avoided easily through proper cleaning procedures. Cleaning and disinfecting procedures vary depending on the equipment and how it is used. Cleaning instructions for diving equipment are provided in the appropriate equipment operations and maintenance manual and PMS maintenance requirement cards.

8-7.6 Chemical Injury. The term "chemical injury" refers to the introduction of a caustic solution from the carbon dioxide scrubber of the UBA into the upper airway of a diver. A caustic alkaline solution results when water leaking into the canister comes in contact with the carbon dioxide absorbent. When the diver is in a horizontal or head down position, this solution may travel through the inhalation hose and irritate or injure the upper airway.

Before actually inhaling the caustic solution, the diver may experience labored breathing or headache, which are symptoms of carbon dioxide buildup in the breathing gas. This occurs because an accumulation of the caustic solution in the canister may be impairing carbon dioxide absorption. If the problem is not corrected promptly, the alkaline solution may travel into the breathing hoses and subsequently be inhaled or swallowed. Choking, gagging, foul taste, and burning of the mouth and throat may begin immediately. This condition is sometimes referred to as a "caustic cocktail". The extent of the injury depends on the amount and distribution of the solution. If the caustic solution enters the mouth, nose, or face mask, the diver must take the steps listed below.

a. Immediately assume an upright position in the water.

b. Depress the manual diluent bypass valve continuously. If the dive is a no-decompression dive, make a controlled ascent to the surface, exhaling through the nose to prevent overpressurization. If the dive requires decompression, shift to an alternative breathing supply. If it is not possible to complete the planned decompression, surface the diver and treat for omitted decompression.

Refer to the appropriate operations and maintenance manual for specific emergency procedures.

If fresh water is available on the surface, rinse the mouth several times. Several mouthfuls should then be swallowed. If only sea water is available, rinse the mouth but do not swallow. Other fluids may be substituted if available, but the use of weak acid solutions (vinegar or lemon juice) is not recommended. ***Do not attempt to induce vomiting.***

As a result of a chemical injury, the diver may have difficulty breathing properly on ascent. He should be observed for signs of an arterial gas embolism and should be treated if necessary. A victim of a chemical injury should be evaluated by a physician or corpsman as soon as possible. Respiratory distress which may result from the chemical trauma to air passages requires immediate hospitalization.

NOTE

Performance of a careful dip test during predive setup is essential to detect system leaks. Additionally, dive buddies shall check each other's equipment carefully before leaving the surface at the start of a dive.

8-8 MEDICATIONS AND DIVING

There are no hard and fast rules for deciding when a medication would preclude a diver from diving. In general, topical medications, antibiotics, and decongestants which do not cause drowsiness would not prevent diving. Transdermal Scopalamine is an effective antiseasick medication which has been shown to have no adverse effects while diving in individuals who can tolerate the drug. Reactions to this drug have been noted in certain susceptible individuals. Therefore, this drug should not be used during diving operations unless the individual has used it at least one time previously without indication of adverse reactions. Individuals who have not used the drug previously, should have a patch applied at least 24 hours before diving operations commence to verify no adverse reactions will occur.

In order to determine if any other drugs would preclude diving, a Diving Medical Officer should be consulted.

SECTION 8B

DIVING DISORDERS REQUIRING RECOMPRESSION THERAPY

Section 8B describes the diagnosis of diving disorders that either require recompression therapy or that may complicate recompression therapy. There are two basic classes of medical emergencies which require treatment by recompression: arterial gas embolism (AGE) and decompression sickness (DCS).

Arterial gas embolism, also called simply gas embolism, may cause rapid deterioration in, which case it must be treated as an extreme emergency. Gas embolism can strike during any dive where underwater breathing equipment is used, even a brief, shallow dive, or one made in a swimming pool. The condition may develop rapidly causing severe symptoms which must be treated quickly. Decompression sickness can be just as serious, but usually develops gradually, even after the completion of a seemingly routine and uneventful dive. However, serious decompression sickness may occur very soon after surfacing and in some cases may be impossible to distinguish from arterial gas embolism. Decompression sickness is not unique to diving. It can affect aviators (altitude bends) or men working in pressure chambers or caissons, but occurs only when decompression (a reduction in the pressure surrounding the body) has taken place.

In the past, treatment of arterial gas embolism was always instituted by direct compression to 165 fsw. Modern experience and research studies have shown that this is not always necessary or desireable. Initial compression to 60 fsw, identical to initial treatment for decompression sickness, will be effective in the majority of cases. Modern reasearch has shown that the symptoms caused by bubbles depend on their ultimate location and not their source. Current treatment recommendations all begin with an initial compression to 60 fsw, with deeper compression depending on the response of the injured individual after initial compression. In order to administer the appropriate recompression treatment, it is necessary to be able to evaluate the stricken diver's initial condition as well as his response to initial therapy. It is also important to understand the causes of arterial gas embolism and decompression sickness as well as other disorders which may accompany or complicate these disorders.

8-9 PULMONARY OVERINFLATION SYNDROMES

Pulmonary overinflation syndromes are disorders which are caused by gas expanding within the lung. The disorders encountered in diving are arterial gas embolism, pneumothorax, mediastinal emphysema, and subcutaneous emphysema.

8-9.1 Arterial Gas Embolism. Arterial gas embolism is caused by entry of gas bubbles into the arterial circulation which then act as blood vessel obstructions called emboli. These emboli are frequently the result of pulmonary barotrauma caused by the expansion of gas taken into the lungs while breathing under pressure and held in the lungs during ascent. The gas might have been retained in the lungs by choice (voluntary breathholding) or by accident (blocked air passages). The gas could have become trapped in an obstructed portion of the lung which has been damaged from some previous disease or accident; or the diver, reacting with panic to a difficult situation, may breathhold without realizing it. If there is enough gas, and if it expands sufficiently, the pressure will force gas through the alveolar walls into surrounding tissues and into the bloodstream. If the gas enters the arterial circulation, it will be dispersed to all organs of the body. The organs which are especially susceptible to arterial gas embolism and which are responsible for the life threatening symptoms are the central nervous system (CNS) and heart. In all cases of arterial gas embolism, associated pneumothorax is possible and should not be overlooked.

Arterial gas embolism, if severe, must be diagnosed quickly and correctly. The supply of blood to the central nervous system is almost always involved, and unless treated promptly and properly by recompression, arterial gas embolism is likely to result in death or permanent brain damage. Because the brain is rapidly affected, definite symptoms of arterial gas embolism usually appear within a minute or two after surfacing.

Dramatic and severe symptoms of arterial gas embolism are usually quite evident and require immediate and prompt treatment. As a basic rule, any diver who has obtained a breath of compressed gas from any source at depth, whether from diving apparatus or from a diving bell, and who surfaces and remains unconscious or loses consciousness within ten minutes of reaching the surface, must be assumed to be suffering from arterial gas embolism. Recompression treatment must be started immediately. A diver who surfaces unconscious and recovers when exposed to fresh air shall receive a neurological evaluation to rule out arterial gas embolism.

Divers surfacing with sensations of tingling or numbness, a sensation of weakness without obvious paralysis, or complaints of difficulty in thinking without obvious confusion, and who are awake or easily arousable, are probably not suffering from a condition which could not await a thorough medical evaluation before beginning recompression. In these cases, there is time to rule out other causes of symptoms by conducting a neurological evaluation. The type and urgency of recompression is dictated by the state of the diver during the initial evaluation as described in Paragraph 8-11.

Other factors to consider in diagnosing arterial gas embolism are:

(1) The onset is usually sudden and dramatic, often occurring within seconds after arrival on the surface or even before reaching the surface. The signs and symptoms may include dizziness, paralysis or weakness in the extremities, large areas of abnormal sensation, blurred vision, or convulsions. During ascent, the diver may have noticed a sensation similar to that of a blow to the chest. The victim may become unconscious without warning and may even stop breathing.

(2) If pain is the only symptom, arterial gas embolism is unlikely and decompression sickness or one of the other pulmonary overinflation syndromes should be considered.

(3) Some symptoms may be masked by environmental factors or by other, less significant, symptoms. A diver who is chilled may not be concerned with numbness in an arm, which may actually be the sign of CNS involvement. Pain from any source may divert attention from other symptoms. The natural anxiety that accompanies an emergency situation, such as the failure of the diver's air supply, might mask a state of confusion caused by an arterial gas embolism to the brain. A diver who is coughing up blood (which could be confused with bloody froth) may be showing signs of ruptured lung tissue, or may have bitten the tongue or experienced sinus or middle ear squeeze.

Appendix H contains a set of guidelines for performing a neurological examination, and an examination checklist to assist nonmedical personnel in evaluating decompression sickness cases.

8-9.1.2 Administering Advanced Cardiac Life Support (ACLS) in the Embolized Diver. Arterial gas embolism with stable pulse and respiration is termed Category I. Arterial gas embolism with absence of pulse and respiration (cardiopulmonary arrest) is termed Category II arterial gas embolism. Category II patients may require advanced cardiac life support (ACLS). ACLS is a difficult medical procedure which requires immediate availability (within 30 minutes) of ACLS equipment and an ACLS-trained physician or paramedical specialist in contact with a physician. ACLS procedures include diagnosis of abnormal heart rhythms and correction with the administration of drugs and electrical countershock (cardioversion or defibrillation). Many ACLS procedures can be administered while the patient is undergoing recompression but electrical countershock must be conducted at atmospheric pressure. Even the use of a cardiac monitor on a patient under pressure may not always be possible. If the patient is pulseless, then a Diving Medical Officer must decide whether to delay recompression until ACLS equipment arrives or to begin recompression to a depth of 60 fsw with the patient undergoing Basic Cardiac Life Support (BCLS). If a Diving Medical Officer cannot be reached or is unavailable, compress to 60 feet, continue BCLS, and attempt to contact a Diving Medical Officer. If recompression is begun and the Diving Medical Officer determines that electrical countershock is necessary, the patient is decompressed to the surface at 30 fpm and electrical countershock is performed. The patient is then recompressed to the recompression treatment depth as directed by the Diving Medical Officer.

CAUTION

If the tender is outside of no-decompression limits, he should not be brought directly to the surface. Either take the decompression stops appropriate to the tender or lock in a new tender and decompress the patient leaving the original tender to complete decompression.

8-9.2 Other Pulmonary Overinflation Syndromes. Expanding gas trapped in the lung may enter tissue spaces, causing mediastinal emphysema, subcutaneous emphysema, or pneumothorax. Suspicion of any of these conditions warrants prompt referral to medical personnel to rule out pneumothorax. Administration of 100-percent oxygen on the surface is appropriate initial treatment for all suspected cases. Recompression is not generally required except for cases of tension pneumothorax occurring during ascent, as discussed in Paragraph 8-9.2.2.

8-9.2.1 Mediastinal and Subcutaneous Emphysema. Mediastinal emphysema is caused by gas expanding in the tissues behind the breast bone. Symptoms include mild to moderate pain under the breast bone, often described as a dull ache or feeling of tightness. The pain is made worse with deep inspiration, coughing, or swallowing. The pain may radiate to the shoulder, neck, or back.

Subcutaneous emphysema results from movement of the gas from the mediastinum to the region under the skin of the neck and lower face. It often goes unnoticed by the diver in mild cases. In more severe cases, the diver may experience a feeling of fullness around the neck and may have difficulty in swallowing. The diver's voice may change in pitch. An observer may note a swelling or apparent inflation of the neck. Movement of the skin near the windpipe or about the collar bone may produce a cracking or crunching sound (crepitation).

Treatment of mediastinal or subcutaneous emphysema with mild symptoms consists of breathing 100-percent oxygen at the surface. If symptoms are severe, shallow recompression may be beneficial. Recompression should only be carried out upon the recommendation of a Diving Medical Officer who has ruled out the occurrence of pneumothorax. Recompression is performed with the diver breathing 100-percent oxygen and using the shallowest depth of relief (usually five or ten feet). An hour of breathing oxygen should be sufficient for resolution, but longer stays may be necessary. Decompression will be dictated by the tender's decompression obligation. The appropriate air table should be used but the ascent rate should not exceed one foot per minute. In this specific case the delay in ascent should be included in bottom time, when choosing the proper decompression table.

8-9.2.2 Pneumothorax. Pneumothorax is usually accompanied by a sharp pain in the chest, shoulder, or upper back that is aggravated by deep breathing. To minimize this pain, the victim will often breathe in a shallow, rapid manner. The victim may appear pale and exhibit a tendency to bend the chest toward the involved side. If a lung has collapsed, it may be detected by listening to both sides of the chest with the ear or a stethoscope. A completely collapsed lung will not produce audible sounds of breathing. In cases of partial pneumothorax, however, breath sounds may be present and the condition must be suspected on the basis of history and symptoms. In some instances, the damaged lung tissue acts as a one-way valve, allowing gas to enter the chest cavity, but not to leave. Under these circumstances, the size of the pneumothorax increases with each breath. This condition is called tension pneumothorax. In simple pneumothorax, the respiratory distress usually does not get worse after the initial gas leakage out of the lung. In tension pneumothorax, however, the respiratory distress worsens with each breath and can progress rapidly to shock and death if the trapped gas is not vented by insertion of a catheter, chest tube or other device desaigned to remove gas from the chest cavity.

Mild pneumothorax can be treated by breathing 100-percent oxygen. Cases of pneumothorax which demonstrate cardiorespiratory compromise may require the insertion of a chest tube, large bore intravenous (IV) catheter or other device designed to remove intrathoracic gas. These devices should only be inserted by personnel trained in their use and the use of other accessory devices (one-way valves, underwater suction, etc.) necessary to safely decompress the thoracic cavity. Divers recompressed for treatment of arterial gas embolism or decompression sickness, who also have a pneumothorax, will experience relief upon recompression. A chest tube or other device and a one-way relief valve may need to be inserted at depth to prevent expansion of the trapped gas during subsequent ascent. If a diver's condition deteriorates rapidly during ascent, especially if the symptoms are respiratory, tension pneumothorax should always be suspected. If a tension pneumothorax is found, recompression to depth of relief is warranted to relieve symptoms until the thoracic cavity can be properly vented. Pneumothorax, if present in combination with arterial gas embolism or decompression sickness, should not prevent immediate recompression therapy. However, a pneumothorax may need to be vented as described above before ascent from treatment depth.

8-9.3 Prevention of Pulmonary Overinflation Syndrome. The potential hazard of the pulmonary overinflation syndromes may be prevented or substantially reduced by careful attention to the following:

(1) Medical selection of diving personnel, with particular attention to elimination of those who show evidence of lung disease or who have a past history of respiratory disorders. Divers who have had a spontaneous pneumothorax have a high incidence of recurrence and should not dive. Divers who have had pneumothorax from other reasons (e.g., surgery, trauma, etc.) should have their fitness for continued diving reviewed by an experienced Diving Medical Officer, in consultation with appropriate respiratory specialists.

(2) Evaluation of the diver's physical condition immediately before a dive. Any impairment of respiration, such as a cold, bronchitis, etc., may be considered as a temporary restriction from diving.

(3) Proper, intensive training in diving physics and physiology for every diver, as well as instruction in the correct use of various diving equipment. Particular attention must be given to the training of SCUBA divers, because SCUBA operations produce a comparatively high incidence of embolism accidents.

(4) A diver must never interrupt breathing during ascent from a dive in which compressed gas has been breathed.

(5) When making an emergency ascent, the diver must exhale continuously. The rate of exhalation must match the rate of ascent. For a free ascent, where the diver uses natural buoyancy to be carried toward the surface, the rate of exhalation must be great enough to prevent embolism, but not so great that the buoyancy factors are cancelled. With a buoyant ascent, where the diver is assisted by an external source of buoyancy such as a life preserver or buoyancy compensator, the rate of ascent may far exceed that of a free ascent. The exhalation must begin before the ascent, and must be a strong, steady forceful exhalation. It is difficult for an untrained diver to execute an emergency ascent properly. It is also often dangerous to train a diver in the proper technique. No ascent training may be conducted unless fully qualified instructors are present, a recompression chamber and Diving Medical Technician are on scene, and a Diving Medical Officer is able to provide an immediate response to an accident. Ascent training is distinctly different from ascent operations as performed by Navy Special Warfare groups. Ascent operations are conducted by qualified divers or combat swimmers. These operations require the supervision of an Ascent Supervisor but operational conditions preclude the use of instructors.

(6) Other factors in the prevention of gas embolism include good planning and adherence to the established dive plan. Trying to extend a dive to finish a task can too easily lead to the exhaustion of the air supply and the need for an emergency ascent. The diver must know and follow good diving practices and keep in good physical condition. The diver must not hesitate to report any illnesses, especially respiratory illnesses such as colds, to the Diving Supervisor or Diving Medical Officer prior to diving.

8-10 DECOMPRESSION SICKNESS

Decompression sickness results from the formation of bubbles in the blood or body tissues and is caused by inadequate elimination of dissolved gas after a dive or other exposure to high pressure. Decompression sickness may also occur with exposure to subatmospheric pressures (altitude exposure), as in an altitude chamber, or sudden loss of cabin pressure in an aircraft. In certain individuals, decompression sickness may occur from no-decompression dives, or decompression dives even when decompression procedures are followed meticulously. Various conditions in the diver or in his surroundings may cause him to absorb an excessive amount of inert gas or may inhibit the elimination of the dissolved gas during normal controlled decompression. Any decompression sickness that occurs must be treated by recompression. The following paragraphs discuss the diagnosis of the various forms of decompression sickness. Once the correct diagnosis is made, the appropriate treatment from Section 8C can be chosen based on the initial evaluation.

A wide range of symptoms may accompany the initial episode of decompression sickness. The diver may exhibit certain signs that only trained observers will identify as decompression sickness. Some of the symptoms or signs will be so pronounced that there will be little doubt as to the cause. Others may be subtle, and some of the more important signs could be overlooked in a cursory examination.

For purposes of deciding the appropriate treatment, symptoms of decompression sickness are generally divided into two categories. Type I decompression sickness (also called pain-only decompression sickness) includes skin symptoms, lymph node swelling, and joint and/or muscle pain and is not life threatening. Type II decompression sickness (also called serious decompression sickness) includes symptoms involving the CNS, respiratory system, or circulatory system. Type II decompression sickness may become life threatening. Because the treatment of Type I and Type II symptoms is different, it is important to distinguish between these two types of decompression sicknesses. Type I and Type II symptoms may or may not be present at the same time.

8-10.1 Type I Decompression Sickness. Type I decompression sickness includes joint pain (musculoskeletal or pain-only symptoms) and symptoms involving the skin (cutaneous symptoms), or swelling and pain in lymph nodes.

8-10.1.1 Musculoskeletal Pain-Only Symptoms. The most common symptom of decompression sickness is joint pain. Other types of pain may occur which do not involve joints. The pain may be mild or excruciating. The most common sites of joint pain are the shoulder, elbow, wrist, hand, hip, knee, and ankle. The characteristic pain of Type I decompression sickness usually begins gradually, is slight when first noticed, and may be difficult to localize. It may be located in a joint or muscle, increasing in intensity, and usually described as a deep, dull ache. The pain may or may not be increased by movement of the affected joint and the limb may be held preferentially in certain positions to reduce the pain intensity (so-called guarding). The hallmark of Type I pain is its dull, aching quality and confinement to particular areas. It is always present at rest; it may or may not be made worse with movement. The pain may lessen if local pressure is applied manually or with a blood pressure cuff.

The most difficult differentiation is between the pain of Type I decompression sickness and the pain resulting from a muscle sprain or bruise. If there is any doubt as to the cause of the pain, assume the diver is suffering from decompression sickness and treat accordingly. Frequent pain may mask other more significant symptoms. Pain should not be treated with drugs in an effort to make the patient more comfortable. The pain may be the only way to localize the problem and monitor the progress of treatment.

Pain in the abdominal and thoracic areas may be localized to joints between the ribs and spinal column, joints between the ribs and sternum, present a shooting-type pain that radiates from the back around the body (radicular or girdle pain), or appear as a vague, aching (visceral) pain. Because it is difficult for nonmedical personnel to differentiate between the Type I joint pain and Type II radicular or visceral pain in the abdominal and thoracic areas, any pain occurring in these regions should be considered by nonmedical personnel as arising from spinal cord involvement. Treat it as Type II decompression sickness, unless it is clearly nonradiating and clearly related to a painful hip or shoulder joint.

Because the treatment of Type I decompression sickness is different from the treatment of Type II decompression sickness, making the distinction between these two categories is important. Musculoskeletal Type I (pain-only) decompression sickness is defined as any extremity joint pain or any nonradiating type of pain or soreness in the extremities. When joint pain occurs, it is not uncommon to have aching pain in the muscles around the joint. Muscle pain may also occur in the back, trunk, or abdominal area in muscles associated with a painful hip or shoulder joint. Any back or trunk pain which cannot be clearly related to a painful hip or shoulder joint, or that radiates down an extremity, should be considered by nonmedical personnel as Type II decompression sickness and treated as such. Divers with Type I symptoms must be monitored carefully because they may progress to Type II or a previously unrecognized Type II symptom may become apparent.

8-10.1.2 Cutaneous (Skin) Symptoms. The most common skin manifestation of diving is itching. Itching by itself is generally transient and does not require recompression. Faint skin rashes may be present in conjunction with itching. These rashes also are transient and do not require recompression. Mottling or marbling of the skin, known as cutis marmorata (marbelization), however, is a symptom of decompression sickness and should be treated by recompression. This condition starts as intense itching, progresses to redness, and then gives way to a patchy, dark bluish discoloration of the skin. The skin may feel thickened. In some cases the rash may be raised.

8-10.1.3 Lymphatic Symptoms. Lymphatic obstruction may occur, creating localized pain in involved lymph nodes and swelling of the tissues drained by these nodes. Recompression will usually provide prompt relief from pain. The swelling, however, may take longer to resolve completely, and may still be present at the completion of treatment.

8-10.2 Type II Decompression Sickness. In the early stages, symptoms of Type II decompression sickness may not be obvious and the stricken diver may consider them inconsequential. The diver may feel fatigued or weak and attribute the condition to overexertion. Even as weakness becomes more severe, the diver may not seek treatment until walking, hearing, or urinating becomes difficult. For this reason, symptoms must be anticipated during the post-dive period and treated before they become too severe.

Many of the symptoms of Type II decompression sickness are the same as those of arterial gas embolism, although the time course is generally different. Since the initial treatment of these two conditions is the same and since subsequent treatment conditions are based on the response of the patient to treatment, treatment should not be delayed unnecessarily in order to make the diagnosis in severly ill patients (see initial evaluation).

Type II, or serious symptoms, are divided into neurological and cardiorespiratory symptoms. Type I symptoms may or may not be present at the same time.

8-10.2.1 Neurological Symptoms. These symptoms may be the result of involvement of any level of the nervous system. Numbness, tingling, and decreased sensation to touch or paresthesias (tingling, "pins and needles", or "electric sensations"), muscle weakness or paralysis, and mental status or motor performance alterations are the most common symptoms. Vertigo, dizziness, ringing in the ears, and hearing loss can also occur. These symptoms may be difficult to distinguish from a round or oval window rupture (Paragraph 8-3.3.2). Disturbances of higher brain function may result in personality changes, amnesia, bizarre behavior, lightheadedness, incoordination, and tremors. Lower spinal cord involvement can cause disruption of urinary function. Some of these signs may be subtle and can be overlooked or dismissed by the stricken diver as being of no consequence.

The occurrence of any neurological symptom is abnormal after a dive, and should be considered a symptom of Type II decompression sickness or arterial gas embolism, unless another specific cause can be found. Normal fatigue is not uncommon after long dives and, by itself, is not usually treated as decompression sickness. If the fatigue is unusually severe, however, it is cause to do a complete neurological examination to ensure there is no CNS involvement.

8-10.2.2 Pulmonary Symptoms. If profuse intravascular bubbling (chokes) occurs, symptoms may develop due to congestion of the lung circulation. Chokes may start as chest pain aggravated by inspiration, and/or as an irritating cough. Increased breathing rate is usually observed. Symptoms of increasing lung congestion may progress to complete circulatory collapse, loss of consciousness, and death if recompression is not instituted immediately.

8-10.2.3 Time Course of Symptoms. Decompression sickness symptoms usually occur within a short period of time following the dive or other pressure exposure. If the controlled decompression during ascent has been shortened or omitted, the diver could be suffering from decompression sickness before reaching the surface.

In analyzing several thousand air dives in a data base set up by the U.S. Navy for developing decompression models, the time of onset of symptoms after surfacing was as follows:

- 42% occurred within one hour
- 60% occurred within three hours
- 83% occurred within eight hours
- 98% occurred within 24 hours

This time distribution is similar to that observed at the Naval Diving and Salvage Training Center.

If a diver has been completely asymptomatic for 48 hours following a dive, symptoms that begin subsequently are probably not caused by decompression sickness.

While a history of diving (or altitude exposure) is necessary for the diagnosis of decompression sickness to be made, the depth and duration of the dive are useful only in establishing if required decompression was missed.

NOTE

> Decompression sickness may occur in divers well within no-decompression limits or who have carefully followed decompression tables.

If the reason for postdive symptoms is firmly established to be due to causes other than decompression sickness or arterial gas embolsim (e.g., injury, sprain, poorly fitting equipment), then recompression is not necessary. If qualified medical personnel are not available to rule out the need for recompression, then it should be carried out if any reasonable doubt as to the cause of symptoms exists.

8-10.4 Altitude Decompression Sickness. Aviators exposed to altitude may experience symptoms of decompression sickness similar to those experienced by divers. The only major difference is that symptoms of spinal cord involvement are rarer and symptoms of brain involvement are more frequent in altitude decompression sickness than hyperbaric decompression sickness. Simple pain, however, accounts for the majority of symptoms.

If only joint pain was present but resolved before reaching one ata from altitude, then the individual may be treated with two hours of 100% oxygen breathing at one atmosphere followed by 24 hours of observation. If symptoms of altitude decompression sickness persist after return to one ata from altitude, the stricken individual should be transferred to a recompression facility for treatment.

If Type II symptoms were present at any time then treatment should be done, even if symptoms resolve at one ata.

Individuals should be kept on 100% oxygen during transfer to the recompression facility. Recompression is carried out identically to that for treating decompression sickness for diving. If symptoms have resolved by the time the individual has reached a recompression facility, they should be examined for any residual symptoms. If a Type II symptom had been present at any time or if even the most minor symptom is present they should be treated as if the original symptoms were still present. If no symptoms are found, and it can be confirmed that the only symptoms ever present were joint pain, then a minimum two hour observation period may be carried out at the surface after which the individual can be assumed symptom free.

8-11 INITIAL EVALUATION AND PATIENT RESPONSE

The goal of recompression therapy is to prevent permanent injury from decompression sickness or arterial gas embolism. While the initial phases of these two diseases are different, the mechanisms by which permanent injury is caused are in many ways similar. Proper application of recompression therapy can abort these mechanisms and in many cases lead to complete resolution of symptoms. Once recompression therapy is begun, choosing the appropriate course to follow will depend mainly on the patient's response to treatment, not the initiating disease. Also, the urgency with which treatment must be initiated will depend on the patient's condition, and less on the cause of the condition.

8-11.1 Initial Evaluation. When a diver is suspected of having decompression sickness or arterial gas embolism, evaluating him for the symptoms described in earlier sections will help establish the diagnosis. However, the length of time one can delay treatment to establish the diagnosis or the degree of urgency necessary in beginning treatment depends on the patient's condition. The patient's initial condition is categorized by the severity of the symptoms, the organ systems affected, and how symptoms are changing with time (evolution).

Severity is judged by how much distress or pain the patient is in. Any obvious disorders of consciousness, mental ability, gait, limb movement, respiration, or circulation are severe symptoms.

The organ systems which are considered are the musculoskeletal system, the central nervous system, the inner ear, and the cardiorespiratory system (heart and lungs).

The evolution describes how symptoms are changing with time. "Static" means little or no change, e.g. the patient's condition has changed little within the past half hour or so. "Progressive" means that the symptoms are worsening or new symptoms are occurring as time goes on. "Spontaneous improvement" means that symptoms are getting better by themselves and "relapsing" means that symptoms are recurring after having improved substantially for some time.

Based on the severity, organ system, and time course, three degrees of urgency are defined.

Category A (Emergent): Symptoms are severe, involve the inner ear, cardiorespiratory system or central nervous system and/or are progressive or relapsing.

These individuals are obviously sick. Neurological signs are present and obvious even without an examination. The diver may be unconscious, confused, or have difficulty breathing. Initial minor symptoms have progressed to more severe symptoms within a relatively short period of time, or may have relapsed. Instituting treatment in these individuals should be considered an extreme emergency. Examination of the patient should not delay treatment or transport. Transportation should be arranged by the fastest means available, with the patient level; feet should not be elevated nor the head lowered. All available resources should be mobilized to ensure treatment will be obtained as soon as possible.

Category B (Urgent): The only severe symptom is pain. Other symptoms are not obvious without conducting an examination. Symptoms are static or have progressed slowly over the past few hours. The patient is not in any distress except possibly from joint pain.

The patient will need recompression as soon as it can be arranged but there is time to conduct a full examination before beginning recompression. Emergency transportation will need to be arranged but high speed ambulance rides or commandeering air transport is not necessary. Recompression is not an extreme emergency and should not be started until all normal chamber preparations are completed. Treatment may be delayed up to 15 minutes to await arrival of a Diving Medical Officer or supporting medical equipment.

Category C (Timely): Symptoms are not severe and not obvious without conducting a detailed examination. Any organ system can be affected but the patient is in no distress. Symptoms are static or progressing slowly over a period of hours.

These patients have time for a more complete diagnostic workup before recompression is started. In these cases there is time to rule out causes of symptoms which will not require recompression. However, only a Diving Medical Officer may make the decision not to treat Category C patients.

These three categories are not inclusive and at times it may be hard to place someone in a single category. If in doubt, treat as if he were in the more urgent category. Additionally, a patient's category may change. Therefore, careful observation is required for each case irrespective of its category. The purpose of categorizing patients based on the initial evaluation is not to decide whether to treat or how to treat. Its purpose is to provide a rational method of deciding how fast treatment must be started and how much time there is to prepare the chamber and conduct medical examinations. It is inappropriate to institute recompression on Category C patients without having taken the time to do an adequate examination just as it would be indefensible to delay treatment to finish a neurological examination in a Category A patient.

8-11.2 Patient Response. All recompressions now begin with initial compression to 60 fsw. After that, decisions are made based on response. "Deterioration" means the patient is in a life-threatening situation. "Progressive" means the patient is getting worse. "Stable" means symptoms are largely unchanged. "Improving" or "relief" means that the patient reports there is a clear decrease in the number or severity of symptoms. "Significant improvement or relief" means that it is clear to personnel other than the patient that the number and/or severity of symptoms have decreased. Complete relief means that no symptoms are reported by the patient or are detected by examination. Training is required to adequately assess patient response, but it can be conducted by nonmedical personnel. However, consultation with a Diving Medical Officer is always desireable.

SECTION 8C

RECOMPRESSION THERAPY

Section 8C covers recompression therapy. Recompression therapy is indicated for the treatment of omitted decompression, decompression sickness, and arterial gas embolism.

The procedures outlined in this chapter are to be performed only by personnel properly trained to use them. Since these procedures cover symptoms ranging from pain to life-threatening disorders, the degree of medical expertise necessary to carry out treatment properly will vary. Certain procedures, such as starting I.V. fluid lines and inserting chest tubes, require special training and should not be attempted by untrained individuals. Treatment tables can be executed without consultation with a Diving Medical Officer, although a DMO must always be contacted at the earliest possible opportunity. Three treatment tables, however, require special consideration. Treatment Table 4 is a long, arduous table that requires constant evaluation of the stricken diver. Treatment Table 7 and Treatment Table 8 allow prolonged treatments for severely ill patients based on the patient's condition throughout the treatment.

Experience has shown that symptoms of severe decompression sickness or arterial gas embolism may occur following seemingly normal dives. This fact, combined with the many operational scenarios under which diving is conducted, means that treatment of severely ill individuals will be required occasionally when qualified medical help is not immediately on scene. Therefore, it is the Diving Supervisor's responsibility to ensure that every member of the diving team:

(1) Be thoroughly familiar with all recompression procedures.

(2) Know the location of the nearest, certified recompression facility.

(3) Know how to contact a qualified Diving Medical Officer if one is not at the site.

Modern communications allow access to medical expertise from even the most remote areas. Emergency consultation is available 24 hours a day with:

- Naval Medical Research Institute (NMRI)
  Bethesda, MD 20814
  Commercial: (301) 295-1839
  Autovon: 295-1839

- Navy Experimental Diving Unit (NEDU)
  321 Bullfinch Rd.
  Panama City, FL 32407-7015
  Commercial: (904) 230-3100
  (904) 235-1668
  Autovon: 436-4351

The recompression procedures described in this chapter are designed to handle most situations which will be encountered operationally. They are applicable to both surface-supplied and SCUBA diving, whether on air, nitrogen-oxygen, helium-oxygen, or 100-percent oxygen. For example, the treatment of arterial gas embolism has little to do with the gas being breathed at the time of the accident. Since all possible conditions cannot be anticipated, additional medical expertise should be sought in all cases of decompression sickness or arterial gas embolism that do not show substantial improvement on standard treatment tables. Treatment of decompression sickness during saturation dives is covered separately in Volume 2, Paragraph 12-23.3, of this manual. Periodic evaluation of

U.S.Navy recompression treatment procedures has shown they are effective in relieving symptoms over 90% of the time when used as published. Deviation from these protocols should be made only in exceptional circumstances.

In addition to individuals suffering from diving disorders, U.S. Navy recompression chambers are also permitted to treat individuals suffering from cyanide poisoning, carbon monoxide poisoning, gas gangrene, smoke inhalation, or arterial gas embolism arising from surgery, diagnostic procedures, or thoracic trauma. If the chamber is to be used for treatment of nondiving related medical conditions other than those listed above, authorization from BUMED-3B1, (202) 653-1182, must be obtained before treatment begins (BUMEDINST 6320.38).

Recompression treatment is designed to accomplish three primary objectives: (1) to compress gas bubbles to a small volume, thus relieving local pressure and restarting blood flow, (2) to allow sufficient time for bubble resorption, and (3) to increase blood oxygen content and thereby oxygen delivery to injured tissues.

Table 8-1 gives the basic rules that must be followed for all recompression treatments. A list of standard treatment tables is given in Table 8-2.

Certain facets of recompression treatment have been mentioned previously, but they are so important that they cannot be stressed too strongly.

(1) Treat promptly and adequately. Adopt the degree of urgency warranted by the patient's condition as outlined in Paragraph 8-11.

(2) The effectiveness of treatment decreases as the length of time between the onset of symptoms and the treatment increases.

(3) Do not ignore seemingly minor symptoms. They can quickly become major symptoms.

(4) Follow the selected treatment table unless changes are recommended by a Diving Medical Officer.

(5) If multiple symptoms occur, treat for the most serious condition. In order of increasing severity, they are: Type I DCS, Type II DCS and AGE.

Recompression in a facility equipped for oxygen breathing is preferred. However, the procedures covered here also address situations where either no chamber is available or where only air is available at the recompression facility. In-water or air recompression treatments are used only when the delay in transporting the patient to a recompression facility having oxygen would cause greater harm.

8-12 PRESCRIBING AND MODIFYING TREATMENTS

When treatments of diving accidents are assisted by personnel other than credentialed Diving Medical Officers (DMOs) that are privileged by the treatment facility Commanding Officer, they must be in compliance with this manual.

Not all Medical Officers are DMOs. The DMO must have graduated from the Diving Medical Officer course taught at the Naval Diving and Salvage Training Center (NDSTC). DMOs will have subspecialty codes of 1605 (Undersea Medical Officer) or 1632 (Hyperbaric Medical Researcher). Saturation Diving Medical Officers have an Additional Qualification Designator (AQD) of 6UD and Submarine Medical Officers an AQD of 6UM. Medical Officers who only complete the short diving medicine course at NDSTC do not receive DMO subspecialty codes but are considered to have the same priveleges as DMOs when treating diving acci-

Table 8-1. Rules for Recompression Treatment.

ALWAYS:
1. Follow the treatment tables accurately, unless modified by a Diving Medical Officer with concurrence of the Commanding Officer.
2. Have a qualified tender in chamber at all times during treatment.
3. Maintain the normal descent and ascent rates as much as possible.
4. Examine the patient thoroughly at depth of relief or treatment depth.
5. Treat an unconscious patient for arterial gas embolism or serious decompression sickness unless the possibility of such a condtion can be ruled out without question.
6. Use air treatment tables only if oxygen is unavailable.
7. Be alert for warning signs of oxygen toxicity if oxygen is used.
8. In the event of oxygen convulsion, remove the oxygen mask and keep the patient from self-harm. Do not force mouth open during convulsion.
9. Maintain oxygen usage within the time and depth limitations prescribed by the treatment table.
10. Check the patient's condition and vital signs periodically. Check frequently if the patient's condition is changing rapidly or the vital signs are unstable.
11. Observe patient after treatment for recurrence of symptoms. Observe two hours for pain-only symptoms, six hours for serious symptoms.
12. Maintain accurate timekeeping and recording.
13. Maintain a well-stocked medical kit at hand.
NEVER:
1. Permit any shortening or other alteration of the tables, except under the direction of a Diving Medical Officer.
2. Wait for a bag resuscitator. Use mouth-to-mouth resuscitation immediately if breathing ceases.
3. Break rhythm during resuscitation.
4. Permit the use of 100-percent oxygen below 60 feet.
5. Fail to treat doubtful cases.
6. Allow personnel in the chamber to a assume cramped position that might interfere with complete blood circulation.

Table 8-2. U.S. Navy Standard Recompression Treatment Tables Using Oxygen (sheet 1 of 2).

Treatment Table	Use for Treatment of	References.
4 Section 8-15.3.4	• Worsening Type II symptoms at 60 feet	Figure 8-2
	• Unresolved arterial gas embolism symptoms after 30 min. at 165 feet	Figure 8-3
	• Recurrance of symptoms 60 feet or deeper	Figure 8-4
5 Section 8-15.3.1	• Type I symptoms releived within 10 min. of arrival at 60 feet with normal pre-treatment neuro exam	Figure 8-2
	• Asymptomotic missed decompression	(Air) Table 8-3 (HeO_2) Table 11-5
	• Treated and resolved in-water symptoms	Figure 8-1 Section 8-15.1
	• Exceeded Sur-D surface interval, no symptoms	Section 8-15.1.1
6 Section 8-15.3.2	• Type I symptoms not resolved within 10 min. at 60 feet or where neuro exam not done	Figure 8-2
	• Recurrance of symptoms shallower than 60 feet	Figure 8-4
	• Type II or arterial gas embolism symptoms responding to an initial 60 foot recompression	Figure 8-3 Figure 8-2
	• Asymptomatic missed decompression	(Air) Table 8-3 (HeO_2) Table 11-5
	• Symptomatic blowup from 60 feet or less	Section 8-13.2
	• Treated but unresolved in-water symptoms	Figure 8-5 Section 8-15.1
6A Section 8-15.3.3	• Arterial gas embolism not responding at 60 feet but resolving within 30 min. at 165 feet where initially 20 min. or less is spent at 60 feet	Figure 8-3
	• Symptomatic blowup from greater than 60 feet	Section 8-13.2
7 Section 8-15.3.5	• Type II or arterial gas embolism symptoms needing more time at 60 feet	Figure 8-2 Figure 8-3 Figure 8-4
	• Arterial gas embolism symptoms releived within 30 min. at 165 feet but where more than 20 min. spent at 60 feet during initial recompression	Figure 8-3
8 Table 11-6	• Deep blowup from surface supplied helium-oxygen dives	Table 11-5 Table 13-11 Section 11-4.10
NOTE 1:	21% Oxygen in Helium may be used instead of air upon the recommendation of a Diving Medical Officer, if available.	
NOTE 2:	Up to 50% Oxygen in Nitrogen mixes may be used to a depth of 165 fsw upon the recommendation of a Diving Medical Officer, if available.	

Table 8-2. U.S. Navy Standard Recompression Treatment Tables When Oxygen Not Available (sheet of 2 of 2).

Treatment Table	Use for Treatment of	References.
1A	• Symptoms using in-water recompression	Section 8-14.2.1
	• Asymptomatic omitted decompression	Table 8-3
	• Type I symptoms relieved at 66 feet or less	Section 8-15.2
	• Exceeded Sur-D surface interval, no symptom	Section 8-15.1.1
2A	• Type I symptoms relieved below 66 feet	Section 8-15.2
	• Asymptomatic omitted decompression	Table 8-3
3	• Type II or arterial gas embolism symptoms relieved within 30 min. at 165 feet	Section 8-15.2
4 Section 8-15.3.4	• Type II or arterial gas embolism symptoms not relieved by 30 min. at 165 feet	Section 8-15.2 Figure 8-3

NOTE: Do not use if Oxygen Tables can be used.

dents. Only those physicians cited in this paragraph may modify the treatment protocols in this manual with the concurrence of the Commanding Officer. Other physicians may assist and advise treatment and care of diving casualties but may not modify recompression procedures.

8-13 OMITTED DECOMPRESSION

Certain emergencies may interrupt or prevent required decompression. Blowup, exhausted air supply, and bodily injury constitute such emergencies. If the diver shows symptoms of decompression sickness or arterial gas embolism, immediate treatment using the appropriate oxygen or air recompression treatment table is essential. Even if the diver shows no symptoms, omitted decompression must be made up in some manner to avert later difficulty.

Omitted decompression may or may not be planned. Planned omitted decompression results when a condition develops at depth which will require the diver to surface before completing all of the decompression stops, and when there is time to consider all available options, ready the recompression chamber, and alert all personnel as to the planned evolution. Equipment malfunctions, diver injury, or sudden severe storms are examples of these situations. In unplanned omitted decompression, the diver suddenly appears at the surface without warning or misses decompression for some unforeseen reason. In either instance, the Surface Decompression Tables may be used to remove the diver from the water, if the surfacing time occurs such that water stops are either not required or have already been completed. When the conditions which permit the use of the Surface Decompression Tables are not fulfilled, the diver's decompression will be compromised. Special care must be taken to detect signs of decompression sickness. The diver must be returned to pressure as soon as possible. For this return to pressure, the use of a recompression chamber is strongly preferred over in-water recompression.

If the diver develops symptoms of decompression sickness during the surface interval, treat in accordance with the procedures in Paragraph 8-14 (no chamber available) or Paragraph 8-15 (chamber available). If the diver has no symptoms of decompression sickness or arterial gas embolism, make up the omitted decompression as described below.

Procedures for dealing with omitted decompression in specific environments are presented in Volume 2, Paragraph 13-6.4 for MK 15/16 diving operations and in Paragraph 11-4.10 for surface-supplied helium-oxygen diving.

8-13.1 Ascent from 20 Feet or Shallower (Shallow Surfacing). If the diver surfaced from 20 feet or shallower, feels well, and can be returned to stop depth within one minute, the diver may complete normal decompression stops. The decompression stop from which ascent occurred is lengthened by one minute. If the one-minute surface interval is exceeded and the diver remains asymptomatic, return the diver to the stop from which the diver ascended and multiply the 20- and/or 10-foot stop times by 1.5. Alternatively, the diver may be placed in a recompression chamber and treated on a Treatment Table 5 (or 1A if no oxygen is available). The diver should be observed for one hour after surfacing and/or completing treatment.

No recompression is required if the diver surfaces from 20 feet or shallower but was within no-decompression limits. The diver should be observed on the surface for one hour.

8-13.2 Ascent from Deeper than 20 Feet (Blowup). Any unexpected surfacing of the diver from depths in excess of 20 feet is considered a blowup. If the diver is within no-decompression limits and asymptomatic, he should be observed for at least one hour on the surface.

Recompression is not necessary unless symptoms develop.

Asymptomatic divers who blowup and who have missed decompression stops are treated by recompression based on the amount of decompression missed as follows:

- **Oxygen Available -** Immediately compress the diver to 60 feet in the recompression chamber. If less than 30 minutes of decompression (total ascent time from the tables) was missed, decompress from 60 feet on Treatment Table 5. If more than 30 minutes of decompression was missed, decompress from 60 feet on Treatment Table 6.

- **Oxygen Not Available -** Compress the diver to 100 feet in the recompression chamber and treat on Table 1A if less than 30 minutes of decompression was missed; compress to 165 feet and treat on Table 2A if more than 30 minutes was missed.

As long as the diver shows no ill effects, decompress him in accordance with the treatment table. Consider any decompression sickness that develops during or after this procedure a recurrence. Try to keep all surface intervals as short as possible (five mintues or less). If an asymptomatic diver who blows up from a decompression dive has more than a five-minute surface interval, he is decompressed from 60 feet on Treatment Table 6 or treated on Table 2A, even if the missed decompression time was less than 30 minutes.

When no recompression facility is available, use the following in-water procedure to make up omitted decompression in asymptomatic divers for ascents from depths below 20 feet.

Recompress the diver in the water as soon as possible (preferably less than a five-minute surface interval). Keep the diver at rest, provide a standby diver, and maintain good communication and depth control. Use the decompression schedule appropriate for the divers depth and bottom time. Follow the procedure below with one minute between stops:

(1) Return the diver to the depth of the first stop.

(2) Follow the schedule for stops 40-fsw and deeper.

(3) Multiply the 30-, 20-, and 10-fsw stops by 1.5.

Table 8-3 summarizes the management of asymptomatic omitted decompression.

If a diver who blows up has any neurological symptoms, he should be compressed immediately in a recompression chamber. If he surfaced from 60 fsw or shallower, compress to 60 fsw and begin Table 6. If he surfaced from a greater depth, compress to 165 fsw and begin treatment on Table 6A. Symptoms developing during the surface interval or during a period of observation on no-decompression dives are treated as described in Paragraph 8-15.

If the blow up occurred from a depth of 165 feet or deeper and if the diver is not responding to recompression to 165 fsw, nonstandard treatment protocols as recommended by the Diving Medical Officer will have to be used in these cases and consultation with NEDU or NMRI is appropriate.

Treatment of symptomatic divers who have surfaced unexpectedly, when no recompression

Table 8-3. Management of Asymptomatic Omitted Decompression.

Depth at Which Ommission Began	Decompression Status	Eligible for Sur-D?	Surface Interval	Action: Chamber Available	Action: No Chamber Available
20 fsw or shallower	No-Decompression	N/A	N/A	Observe on surface for 1 hr.	
	Decompression Stops Required	Yes	Less than 5 min.	Use Surface Decompression Tables	Perform Chamber stops in water (Note 1)
		No	Less than 1 min.	Return to depth of stop. Increase stop time 1 min. Resume decompression.	
		No	Greater than 1 min.	Return to depth of stop. Multiply 20 and 10-foot stop times by 1.5. Or: Treatment Table 5 (1A) for surface interval less than 5 min. Or: Treatment Table 6 (2A) for surface interval greater than 5 min.	
Deeper than 20 fsw	No-Decompression	N/A	N/A	Observe on surface for 1 hr.	
	Decompression Stops Required	Yes	Less than 5 min.	Use Surface Decompression Tables	Perform chamber stops in water (Note 1)
	Decompression Stops Required (Less than 30 min. missed)	No No	Less than 5 min. Greater than 5 min.	Treatment Table 5 (1A) (Note 2) Treatment Table 6 (2A) (Note 2)	Descend to depth of first stop. Follow the schedule to 30-fsw. Multiply 30, 20 and 10 fsw stops by 1.5.
	Decompression Stops Required (Greater than 30 min.)	No	Any	Treatment Table 6 (2A) (Note 2)	

Notes:

1. Sur-D Air only.
2. If a diver missed a stop deeper than 60 feet and oxygen is available, first compress to the depth of the first missed stop. Double this stop, then decompress to 60 feet using the appropriate decompression schedule doubling all stop times. Decompress from 60 feet on Treatment Table 5 or 6 as appropriate. If oxygen is unavailable, treat on a full Treatment Table 1A or 2A as appropriate.

chamber is on site, is difficult. Immediate transportation to a recompression facility is indicated; if this is impossible, the guidelines in Paragraph 8-14 may be useful.

8-14 RECOMPRESSION TREATMENTS WHEN NO RECOMPRESSION CHAMBER IS AVAILABLE

In the event that the diving facility is not equipped with a recompression chamber, the Diving Supervisor has two alternatives. If recompression of the patient is not immediately necessary, the diver may be transported to the nearest certified recompression chamber for treatment (the location of the nearest certified recompression chamber and Diving Medical Officer must be included in the data collected during the planning phase of the dive, Chapter Four).

If immediate recompression treatment is considered necessary, the patient must be treated in the water. The hazards involved in this procedure must be weighed carefully against the complications which may result if treatment is delayed. As a general rule, always try to get to the nearest certified recompression chamber, even if it is at considerable distance. Use in-water recompression only as a last resort. In an emergency, an uncertified chamber may be used if, in the opinion of the Diving Supervisor, it is safe to operate.

8-14.1 Transporting the Patient. In certain instances, some delay may be acceptable while the patient is transported to a recompression chamber. While moving the patient to a recompression chamber, the patient should be kept lying horizontally. Do not put the patient head-down. Unconscious patients should be turned on their left side to prevent aspiration should vomiting occur. Additionally, the patient should be kept warm, and the condition monitored constantly for signs of blocked airway, cardiac arrest, cessation of breathing, or shock. Always keep in mind that a number of conditions may exist at the same time. For example, the victim may be suffering from both decompression sickness and severe internal injuries.

Always have the patient breathe 100-percent oxygen during transport, if available. If symptoms of decompression sickness or arterial gas embolism are relieved or improve after breathing 100-percent oxygen, the patient should still be treated as if the original symptom(s) were still present. Always ensure the patient is adequately hydrated. Give fluids by mouth if the patient is able to take them. Otherwise, intravenous fluids should be started before transport (paragraph 8-15.4.2). Patients are adequately hydrated when they have urinated with a full bladder. If the patient must be transported, initial arrangements should have been made well in advance of the actual diving operations. These arrangements, which would include an alert notification to the recompression chamber and determination of the most effective means of transportation, should be posted on the Job Site Emergency Checklist (Chapter Four) for instant referral.

If the patient is moved by helicopter or other unpressurized aircraft, the aircraft should be flown as low as safely possible, preferably less than 1,000 feet. Any unnecessary altitude means an additional reduction in external pressure and possible additional symptom severity or complications. If available, always use aircraft which can be pressurized to one atmosphere.

Call ahead to ensure that the chamber will be ready and that qualified medical personnel will be standing by. If two-way communications can be established, obtain consultation with the doctor as the patient is being transported.

8-14.2 In-Water Recompression.
Recompression in the water should be considered an option of last resort, to be used only when no recompression facility is on site and there is no prospect of reaching a recompres-

sion facility within 12 hours. In divers with severe Type II symptoms, or symptoms of arterial gas embolism (e.g., unconsciousness, paralysis, vertigo, respiratory distress, shock, etc.), the risk of increased harm to the diver from in-water recompression probably outweighs any anticipated benefit. Generally, these individuals should not be recompressed in the water, but should be kept at the surface on 100-percent oxygen, if available, and evacuated to a recompression facility no matter what the delay.

For less life-threatening cases, have the stricken diver begin breathing 100-percent oxygen immediately if it is available on site. Continue breathing oxygen at the surface for 30 minutes before deciding to recompress in the water. If symptoms stabilize, improve or relief on 100-percent oxygen is noted, do not attempt in-water recompression unless symptoms reappear with their original intensity or worsen. Continue breathing 100-percent oxygen as long as supplies last, up to a maximum time of six hours. If surface oxygen proves ineffective after 30 minutes, begin in-water recompression.

8-14.2.1 In-Water Recompression Using Air. In-water recompression using air is always less preferable than using oxygen.

A. Follow Treatment Table 1A as closely as possible.

   (1) Use either a full face mask or, preferably, a surface-supplied UBA. Never recompress a diver in the water using a SCUBA with a mouthpiece unless it is the only breathing source available.

   (2) Maintain constant communication.

B. Keep at least one diver with the patient at all times. Plan carefully for shifting UBAs or cylinders. Have an ample number of tenders topside and at intermediate depths.

C. If the depth is inadequate for full treatment according to Treatment Table 1A:

   (1) Recompress the patient to the maximum available depth.

   (2) Remain at maximum depth for 30 minutes.

   (3) Decompress according to Treatment Table 1A. Do not use stops shorter than those of Treatment Table 1A.

8-14.2.2 In-Water Recompression Using Oxygen. If a 100-percent oxygen rebreather is available and individuals at the dive site are trained in its use, the following in-water recompression procedure may be used instead of Table 1A.

(1) Put the stricken diver on the UBA and have him purge the apparatus at least three times with oxygen.

(2) Descend to a depth of 30 feet with a standby diver.

(3) Remain at 30 feet, at rest, for 60 minutes for Type I symptoms and 90 minutes for Type II symptoms. Ascend to 20 feet even if symptoms are still present.

(4) Decompress to the surface by taking 60-minute stops at 20 feet and 10 feet.

(5) After surfacing, continue breathing 100-percent oxygen for an additional three hours.

(6) If symptoms persist or recur on the surface, arrange for transport to a recompression facility no matter what the delay.

The occurrence of Type II symptoms after in-water recompression is an ominous sign and could progress to severe, debilitating decompression sickness. It should be considered life-threatening. Operational considerations and remoteness of the dive site will dictate the speed with which the diver can be evacuated to a recompression facility.

8-14.3 Symptoms During Decompression (No Chamber Available). Development of decompression sickness in the water is uncommon when U.S. Navy decompression procedures are followed, but when it does occur it is likely to be at shallow stops. The symptoms are usually Type I and respond quickly to minimal recompression. Follow the flowchart in Figure 8-1 for proper management. Only recompress an additional 10 feet if no significant improvement was noted after the first 10 fsw recompression. Remain at treatment depth 30 minutes in addition to any required decompression stop time. Shift diver to 100-percent oxygen at depths 30 feet and shallower if possible. If symptoms persist after surfacing, have the diver breathe 100-percent oxygen while arranging evacuation to a recompression facility. Do not conduct in-water recompression for residual symptoms after surfacing. Once a recompression facility is reached, any symptoms are treated as a recurrence of Type II symptoms.

8-15 RECOMPRESSION TREATMENTS WHEN CHAMBER AVAILABLE

A list of the standard treatment tables described in this chapter is given in Table 8-2. Oxygen Treatment Tables are more effective and, therefore, preferable over Air Treatment Tables. Treatment Table 4 can be used with or without oxygen but should always be used with oxygen if it is available.

8-15.1 Symptoms During Decompression and Surface Decompression (Recompression Chamber Available). If symptoms of decompression sickness occur in the water during decompression, follow the flowchart in Figure 8-1. After completing recompression treatment, observe the diver for at least six hours. If any symptoms recur, treat as a recurrence of Type II symptoms. As an option, the on-site Diving Supervisor may elect not to recompress the diver 10 feet in the water, but to remove the diver from the water when decompression risks are acceptable and treat him in the chamber. When this is done, the surface interval should be five minutes or less, with the diver always treated as having Type II symptoms.

Treatment of decompression sickness arising in the water in specific operational environments is presented in Volume 2, Paragraph 11-4.13 for surface-supplied helium-oxygen dives and Paragraph 13-7.5 for MK 15/16 diving operations.

If surface decompression procedures are used, symptoms of decompression sickness may occur during the surface interval. Because neurological symptoms cannot be ruled out during this short period, the symptomatic diver is treated as having Type II symptoms, even if the only complaint is pain.

8-15.1.1 Treating for Exceeded Sur-D Surface Interval. If the prescribed surface interval is exceeded but the diver remains asymptomatic, the diver is treated with a Treatment Table 5, or Treatment Table 1A if no oxygen is available. If the diver becomes symptomatic, the diver is treated as if Type II symptoms were present. Any symptoms occurring during the chamber stops of Surface Decompression Tables are treated as recurrences in accordance with Figure 8-4.

8-15.2 Recompression Treatments When Oxygen Is Not Available. If no oxygen is available, select the appropriate Air Treatment Table in accordance with flowcharts 8-8, 8-11, 8-12 and 8-13.

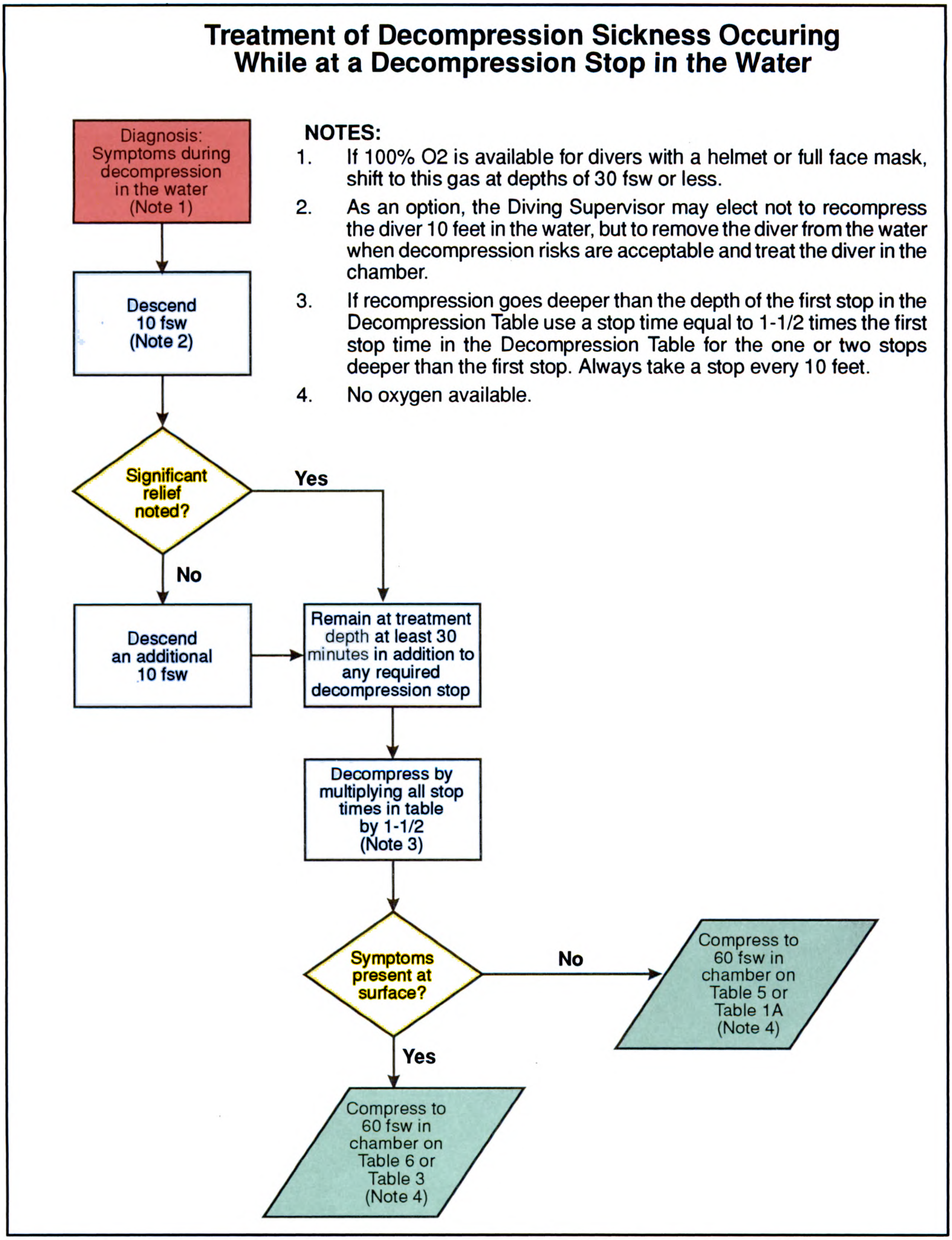


Figure 8-1. Treatment of Decompression Sickness Occurring While at a Decompression Stop in the Water.

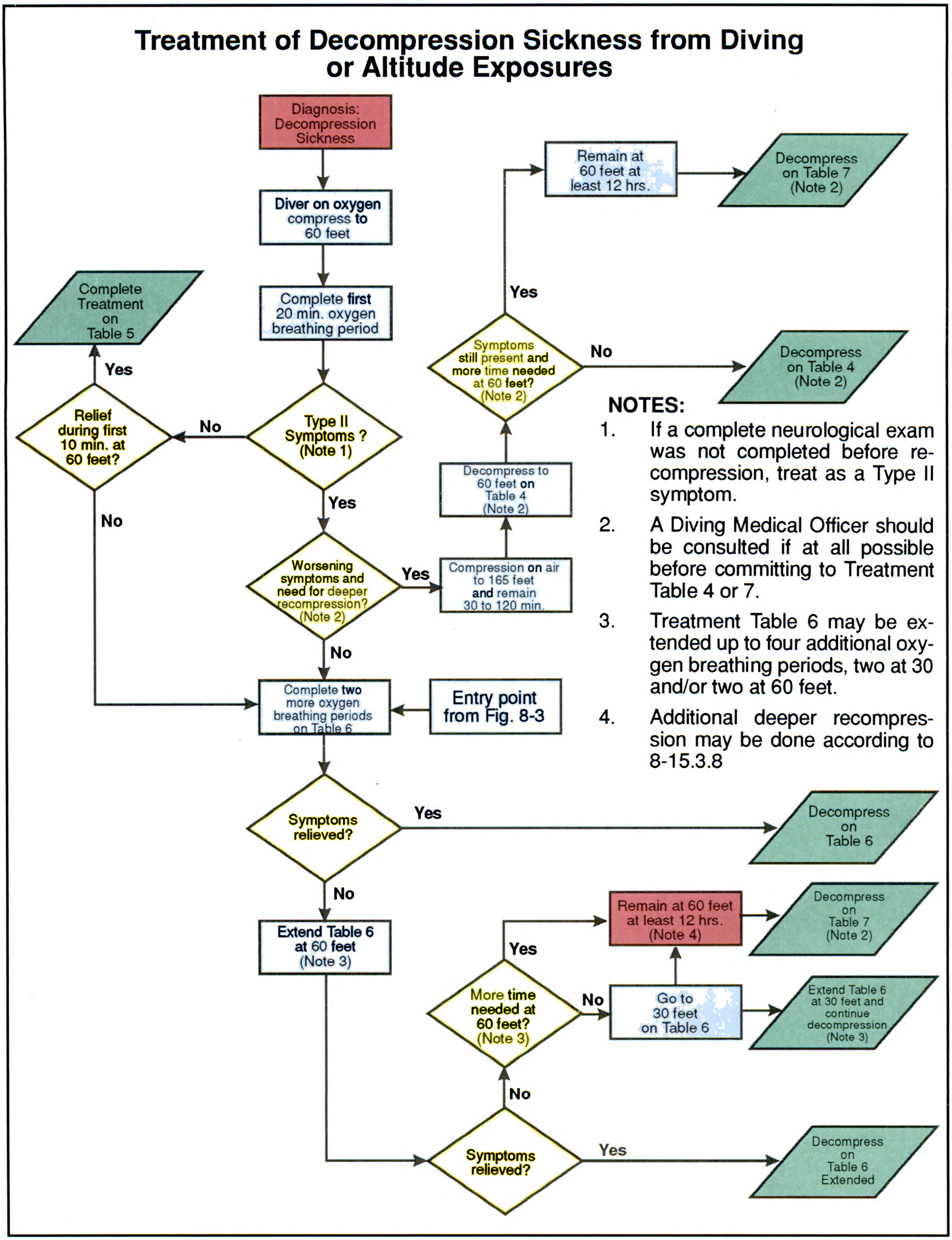
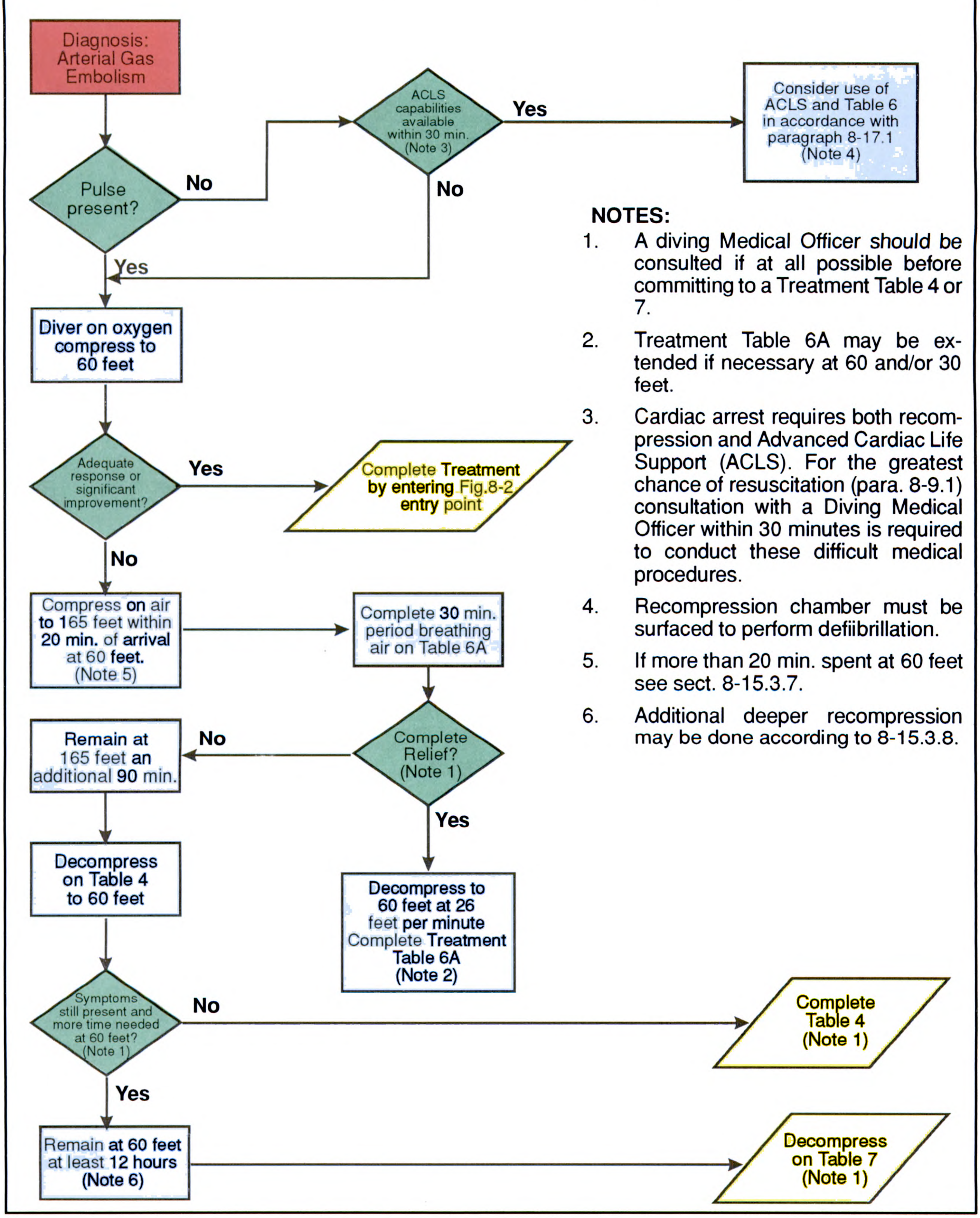


Figure 8-2. Decompression Sickness Treatment from Diving or Altitude Exposures.

Treatment of Arterial Gas Embolism



NOTES:

1. A diving Medical Officer should be consulted if at all possible before committing to a Treatment Table 4 or 7.
2. Treatment Table 6A may be extended if necessary at 60 and/or 30 feet.
3. Cardiac arrest requires both recompression and Advanced Cardiac Life Support (ACLS). For the greatest chance of resuscitation (para. 8-9.1) consultation with a Diving Medical Officer within 30 minutes is required to conduct these difficult medical procedures.
4. Recompression chamber must be surfaced to perform defiibrillation.
5. If more than 20 min. spent at 60 feet see sect. 8-15.3.7.
6. Additional deeper recompression may be done according to 8-15.3.8.

Figure 8-3. Treatment of Arterial Gas Embolism.

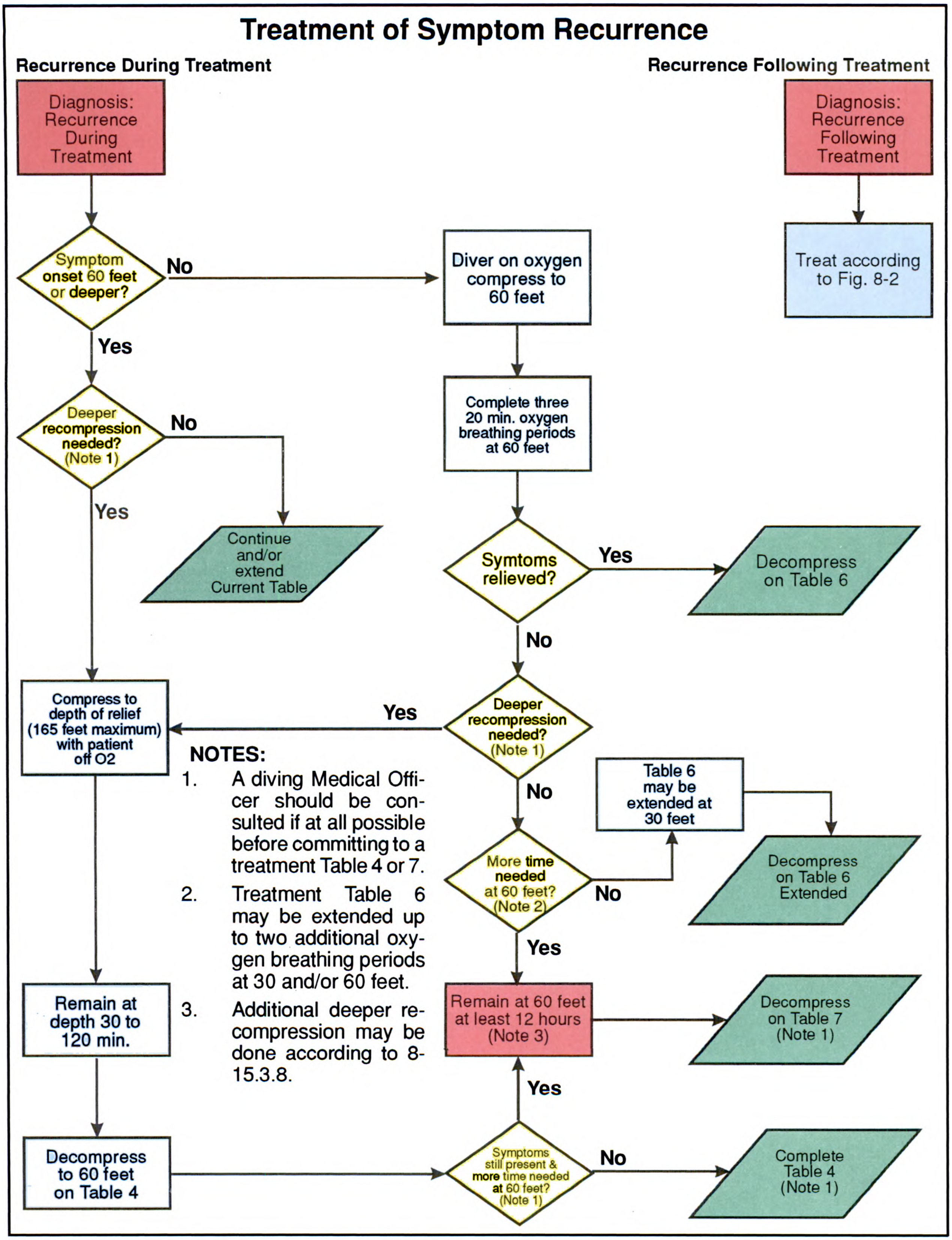


Figure 8-4. Treatment of Symptom Recurrence.

Treatment Table 5

1. Descent rate - 25 ft/min.
2. Ascent rate - 1 ft/min. Do not compensate for slower ascent rates. Compensate for faster rates by halting the ascent.
3. Time at 60 feet begins on arrival at 60 feet.
4. If oxygen breathing must be interrupted, because of CNS Oxygen Toxicity, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption (see paragraph 8.15.4.1)
5. If Oxygen breathing must be interrupted at 60 feet, switch to Table 6 upon arrival at the 30-foot stop.
6. Tender breathes 100% O_2 during the 30 foot stop and during ascent to the surface.

TABLE 5 DEPTH/TIME PROFILE

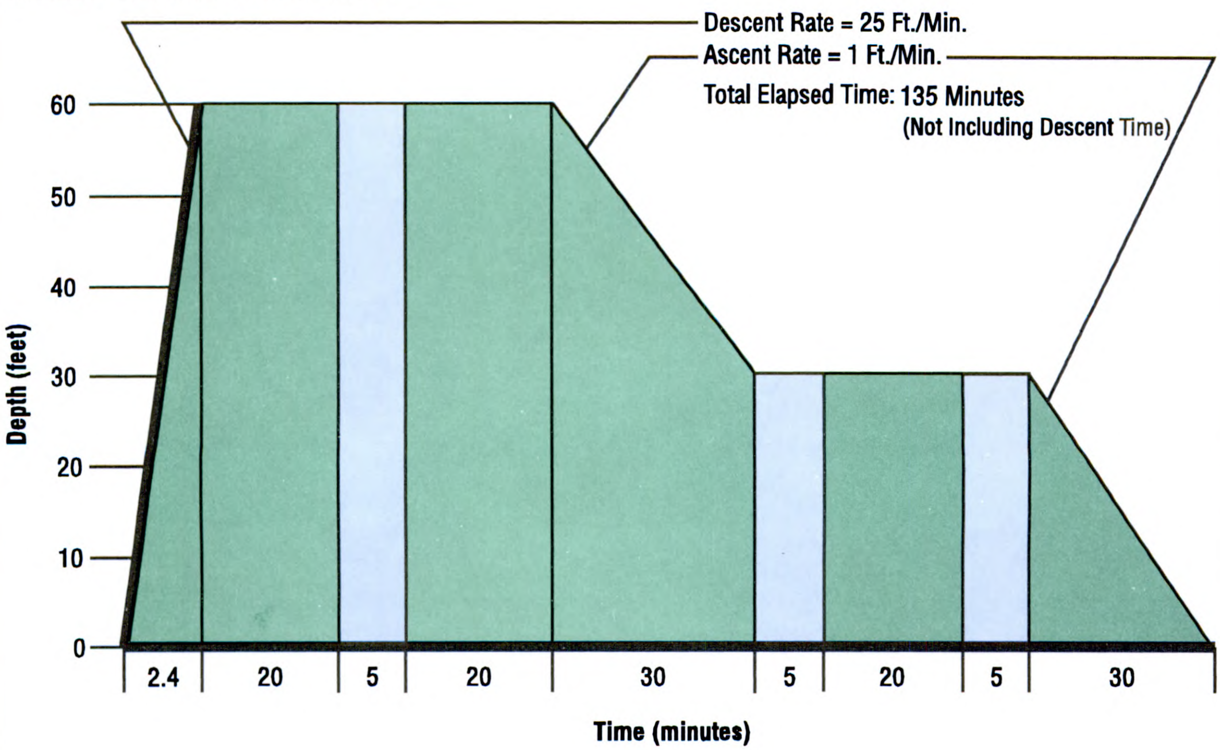


Figure 8-5. Treatment Table 5.

Treatment Table 6

1. Descent rate - 25 ft/min.
2. Ascent rate - 1 ft/min. Do not compensate for slower ascent rates. Compensate for faster rates by halting the ascent.
3. Time at 60 feet begins on arrival at 60 feet.
4. If oxygen breathing must be interrupted because of CNS Oxygen Toxicity, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption (see paragraph 8.15.4.1).
5. Table 6 can be lengthed up to 2 additional 25-minute periods at 60 feet (20 minutes on oxygen and 5 minutes on air), or up to 2 additional 75-minute periods at 30 feet (15 minutes on air and 60 minutes on oxygen), or both.
6. Tender breathes 100% O_2 during the last 30 min. at 30 fsw and during ascent to the surface for an unmodified table or where there has been only a single extension at 30 or 60 feet. If there has been more than one extension the O_2 breathing at 30 feet is increased to 60 min. If the tender has had a hyperbaric exposure within the past 12 hours an additional 60 min. O_2 period is taken at 30 feet.

TABLE 6 DEPTH/TIME PROFILE

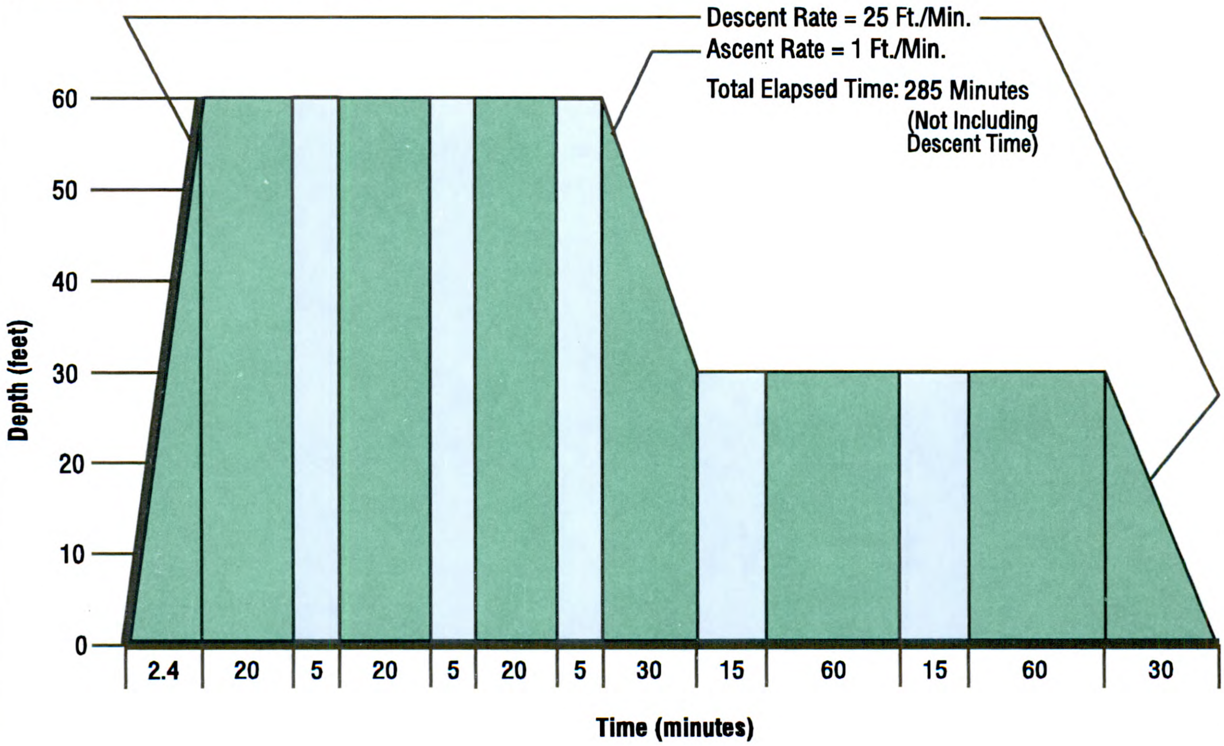


Figure 8-6. Treatment Table 6.

Treatment Table 6A

1. Descent rate - 25 ft/min.
2. Ascent rate - 1 ft/min. Do not compensate for slower ascent rates. Compensate for faster rates by halting the ascent.
3. Time at 165 feet - includes compression time.
4. Table begins with initial compression to 165 feet. If initial treatment was at 60 feet, up to 20 min. may be spent at 60 feet before compression to 165 feet. If compression to 165 feet occurs after spending more than 20 min. at 60 feet, switch to Table 7 upon return to 60 feet.
5. If a chamber is equipped with a high O_2 Nitrox mix it may be administered at 165 fsw and shallower as prescribed by a Diving Medical Officer.
6. If oxygen breathing must be interrupted because of CNS Oxygen Toxicity, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption (see paragraph 8.15.4.1).
7. Table 6A can be lengthed up to 2 additional 25-minute periods at 60 feet (20 minutes on oxygen and 5 minutes on air), or up to 2 additional 75-minute periods at 30 feet (60- minutes on oxygen and 15 minutes on air), or both.
8. Tenders breath 100% O_2 for the last 60 min. at 30 feet and during ascent to the surface at a minimum on all treatments. If the tender has had a hyperbaric exposure within the past 12 hours an additional 60 min. O_2 period is taken at 30 feet.
9. If complete relief is not obtained within 30 minutes at 165 feet, switch to Table 4. Consult with a Diving Medical Officer before switching if possible.

TABLE 6A DEPTH/TIME PROFILE

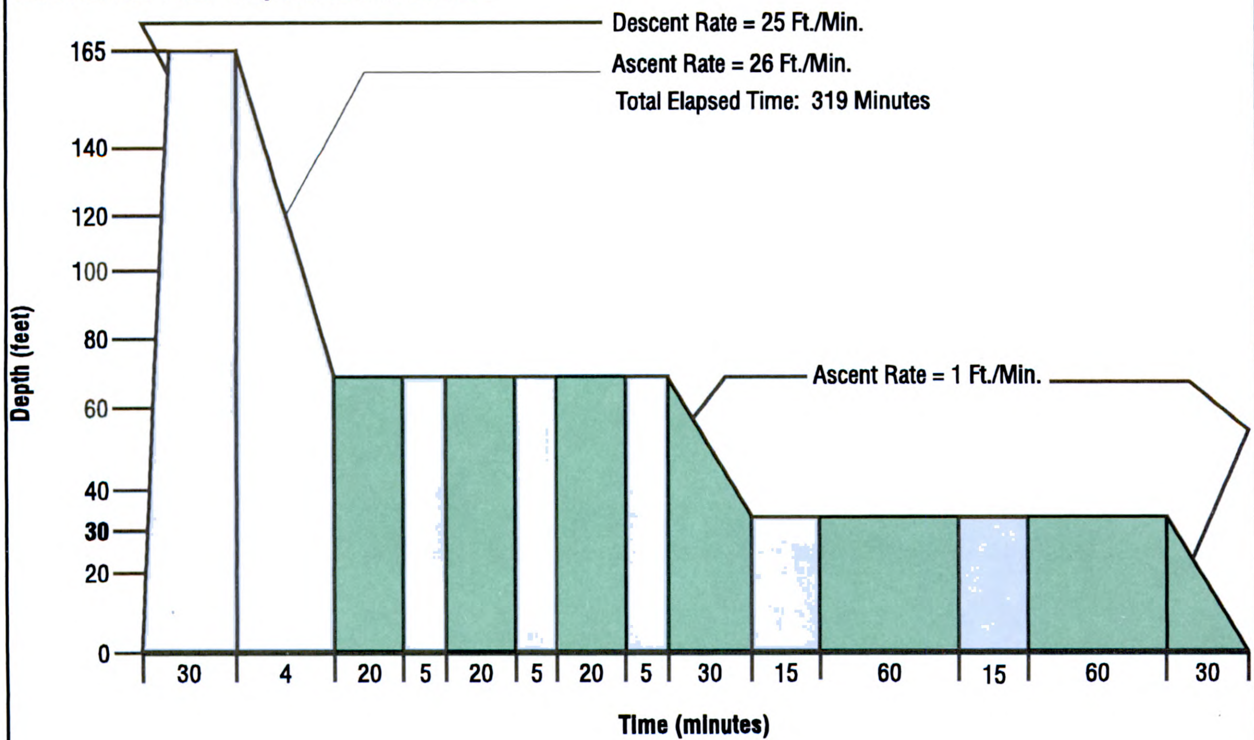


Figure 8-7. treatment Table 6A.

Treatment Table 4

1. Descent rate - 25 Ft./Min.
2. Ascent rate - 1 minute between stops.
3. Time at 165 feet - includes compression.
4. If only air is available, decompress on air. If oxygen is available, patient begins oxygen breathing upon arrival at 60 feet with appropriate air breaks. Both tender and patient breathe oxygen beginning 2 hours before leaving 30 feet. (see paragraph 8.15.3.4).
5. Ensure life support considerations can be met before committing to a Table 4. (see paragraph 8.15.5) Internal chamber temperature should be below 85°F.
6. If oxygen breathing is interrupted, no compensatory lengthing of the table is required.
7. If switching from a Treatment Table 6A or 3 at 165 feet, stay the full 2 hours at 165 feet before decompressing.
8. If the chamber is equipped with a high O_2 nitrox mix it may be administered at 165 fsw and shallower as prescribed by the Diving Medical Officer.

TABLE 4 DEPTH/TIME PROFILE

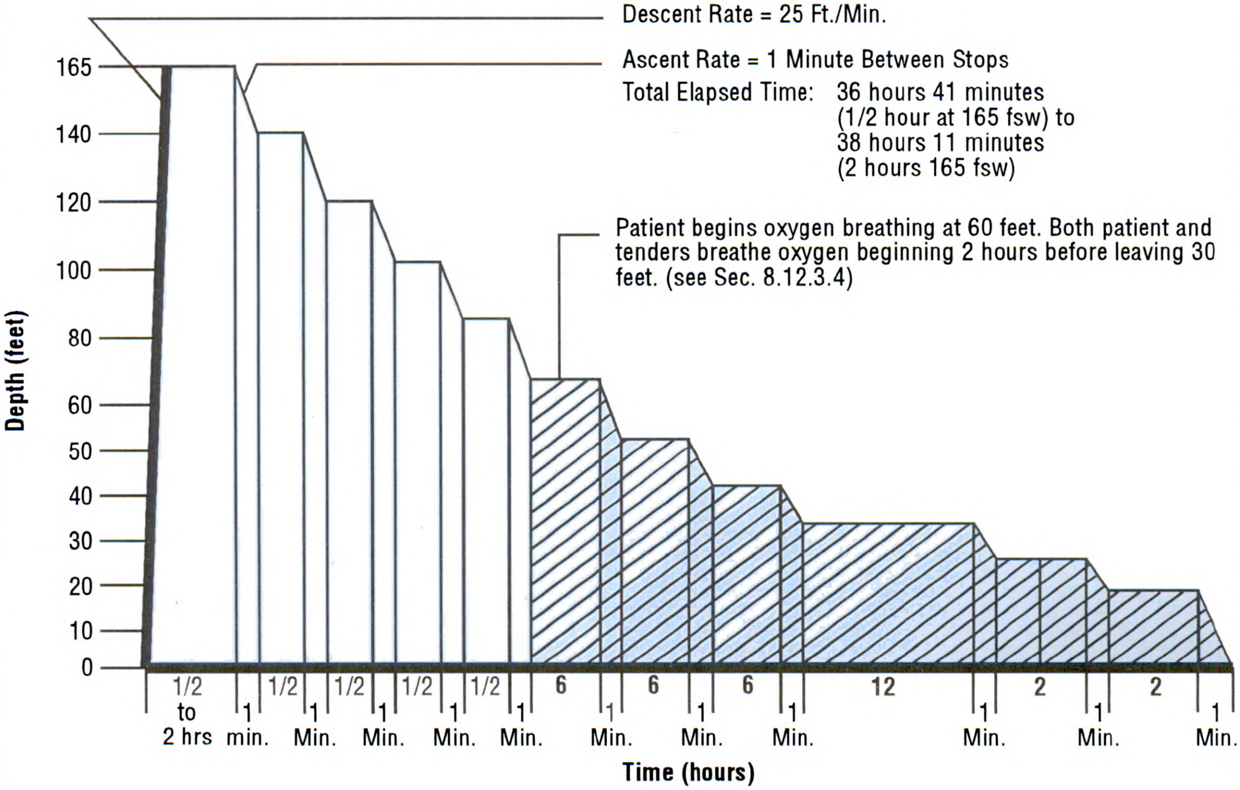


Figure 8-8. Treatment Table 4.

Treatment Table 7

1. Table begins upon arrival at 60 feet. Arrival at 60 feet is accomplished by initial treatment on Table 6, 6A or 4. If initial treatment has progressed to a depth shallower than 60 feet, compress to 60 feet at 25 ft./min. to begin Table 7.
2. Maximum duration at 60 feet is unlimited. Remain at 60 feet a minimum of 12 hours unless overriding circumstances dictate earlier decompression.
3. Patient begins oxygen breathing periods at 60 feet. Tender need breathe only chamber atmosphere throughout. If oxygen breathing is interrupted, no lengthening of the table is required.
4. Minimum chamber O_2 concentration is 19%. Maximum CO_2 concentration is 1.5% SEV (11.4 mmHg). Maximum chamber internal temperature is 85°F (paragraph 8.15.5.4).
5. Decompression starts with a 2 foot upward excursion from 60 to 58 feet. Decompress with stops every 2 feet for times shown in profile below. Ascent time between stops is Approximately 30 seconds. Stop time begins with ascent from deeper to next shallower step. Stop at 4 feet for 4 hours and then ascend to the surface at 1 ft./min.
6. Ensure chamber life support requirements can be met before committing to a Treatment Table 7.
7. See paragraph 8.15.3.5 for details.
8. If the chamber is equipped with 50/50 nitrox mix it may be administered at 165 fsw and shallower as prescribed by the Diving Medical Officer.

TREATMENT TABLE 7 DEPTH/TIME PROFILE

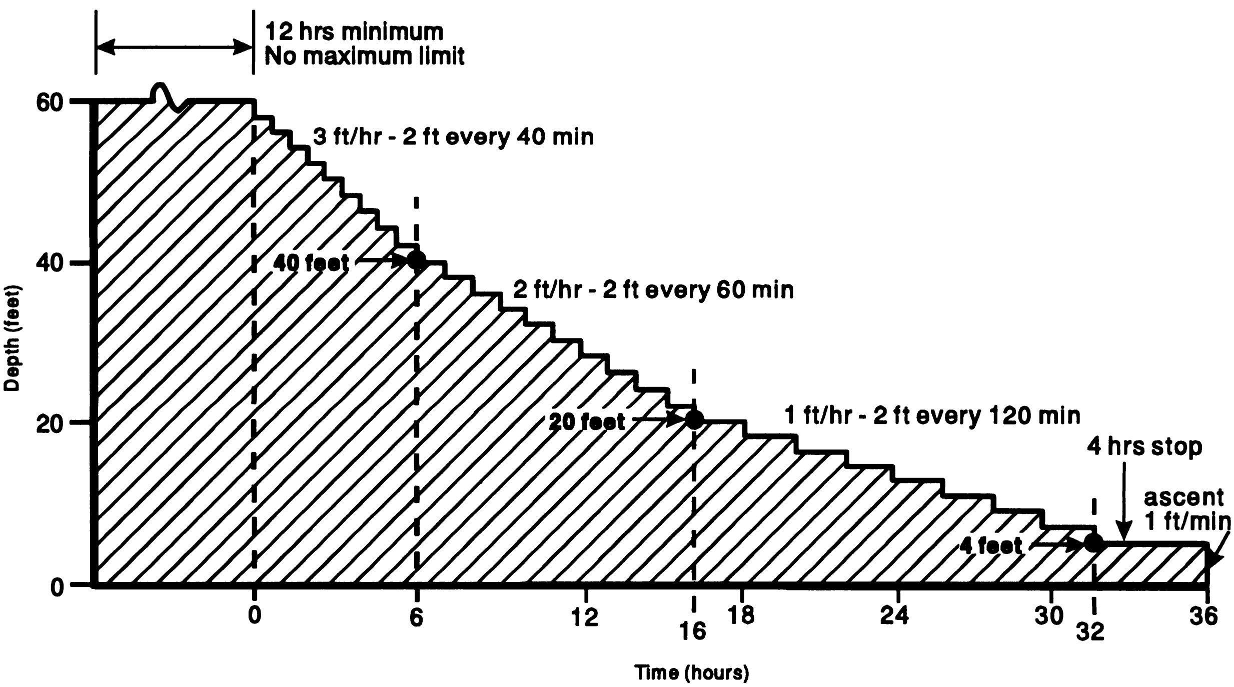


Figure 8-9. Treatment Table 7.

Treatment Table 8

1. Enter the table at the depth which is exactly equal to or next greater than the deepest depth attained in the recompression. The descent rate is as fast as tolerable.
2. The maximum time that can be spent at the deepest depth is shown in the second column. The maximum time for 225 fsw is 30 minutes; for 165 fsw, three hours. For an asymptomatic diver, the maximum time at depth is 30 minutes for depths exceeding 165 fsw and two hours for depths equal to or shallower than 165 fsw.
3. Decompression is begun with a 2-fsw reduction in pressure if the depth is an even number. Decompression is begun with a 3-fsw reduction in pressure if the depth is an odd number. Subsequent stops are carried out every 2 fsw. Stop times are given in column three. The stop time begins when leaving the previous depth. Ascend to the next stop in approximately 30 seconds.
4. Stop times apply to all stops within the band up to the next quoted depth. For example, for ascent from 165 fsw, stops for 12 minutes are made at 162 fsw, and at every two-foot interval to 140 fsw. At 140 fsw, the stop time becomes 15 minutes. When traveling from 225 fsw, the 166 foot stop is five minutes; the 164 foot stop is 12 minutes. Once begun, decompression is continuous. For example, when decompressing from 225 feet, ascent is not halted at 165 fsw for three hours. However, ascent maybe halted at 60 fsw and shallower for any desired period of time.
5. While deeper than 165 fsw, a helium-oxygen mixture with 16-21 percent oxygen maybe breathed by mask to reduce narcosis. At 165 fsw and shallower, a 60-percent helium/40-percent oxygen mixture or a 60-percent nitrogen/40 percent oxygen mixture maybe given to the diver as a treatment gas. At 60 fsw and shallower, pure oxygen maybe given to the diver as a treatment gas. For all treatment gases (HeO_2, N_2O_2, and O_2), a schedule of 25 minutes on gas and five minutes on chamber air should be followed for a total of four cycles. Additional oxygen maybe given at 60 fsw after a two-hour interval of chamber air. See Treatment Table 7 for guidance.
6. A high O_2 treatment mix can be used at treatment depth and during decompression as prescribed by a Diving Medical Officer.
7. To avoid loss of the chamber seal, ascent maybe halted at 4 fsw and the total remaining stop time of 240 minutes taken at this depth. Ascend directly to the surface upon completion of the required time.
8. Total ascent time from 225 fsw is 56 hours, 29 minutes. For a 165-fsw recompression, total ascent time is 53 hours, 52 minutes, and for a 60-fsw recompression, 36 hours, 0 minutes.

Depth (fsw)	**Max Time at Initial Treatment Depth (hours)**	**2-fsw Stop Times (minutes)**
225	0.5	5
165	3	12
140	5	15
120	8	20
100	11	25
80	15	30
60	Unlimited	40
40	Unlimited	60
20	Unlimited	120

Figure 8-10. Treatment Table 8.

Air Treatment Table 1A

1. Descent rate - 25 ft/min.
2. Ascent rate - 1 minute between stops.
3. Time at 100 feet - includes time from the surface.
4. If the piping configuration of the chamber does not allow it to return to atmospheric pressure from the 10-foot stop in the one minute specified, disregard the additional time required.

TABLE 1A DEPTH/TIME PROFILE

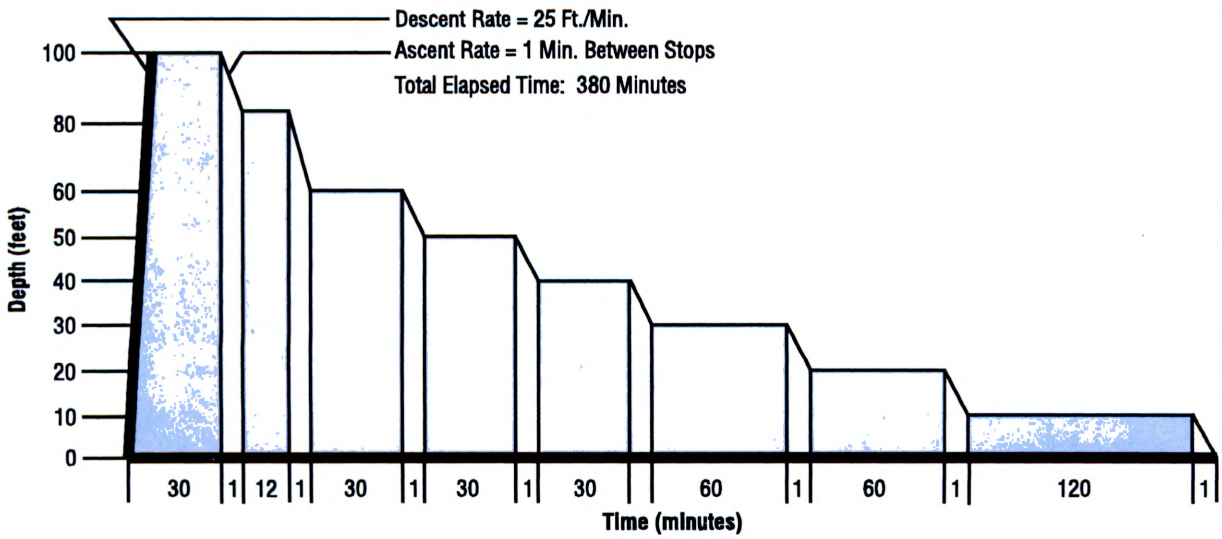


Figure 8-11. Air Treatment Table 1A.

Air Treatment Table 2A

1. Descent rate - 25 ft/min.
2. Ascent rate - 1 minute between stops.
3. Time at 165 feet - includes time from the surface.

TABLE 2A DEPTH/TIME PROFILE

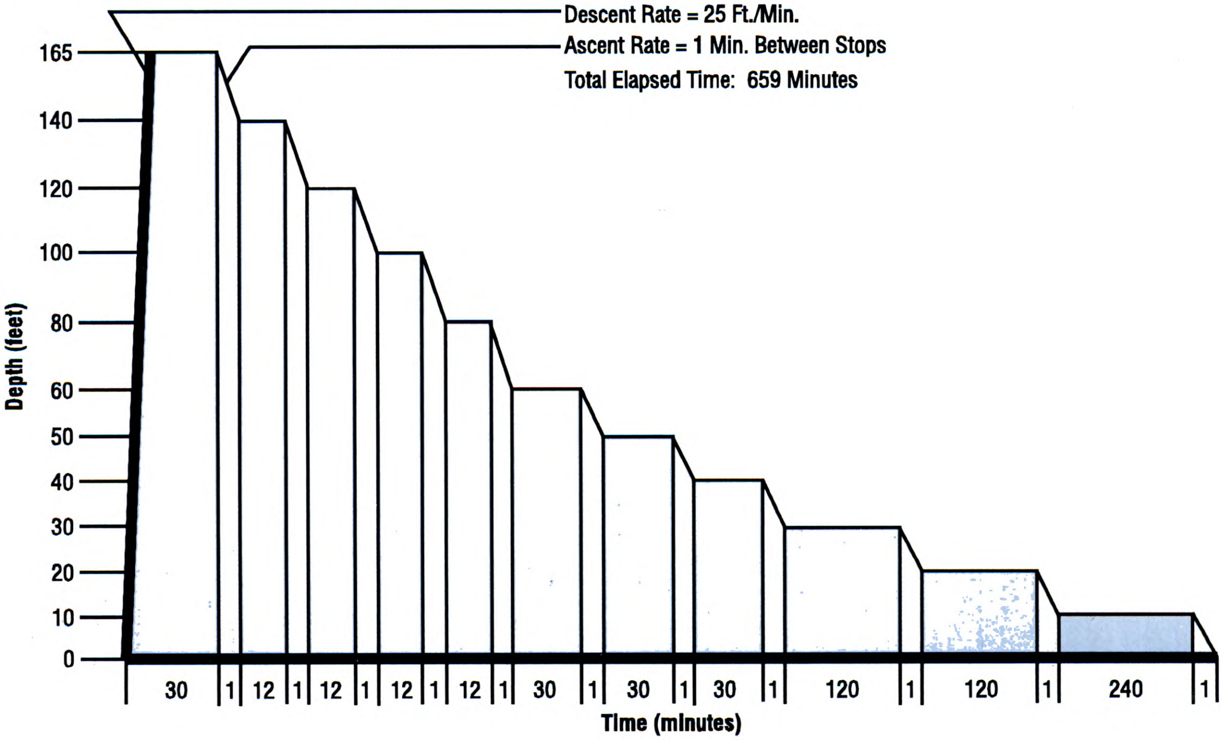


Figure 8-12. Air Treatment Table 2A.

Air Treatment Table 3

1. Descent rate - 25 ft/min.
2. Ascent rate - 1 minute between stops.
3. Time at 165 feet - includes time from the surface.

TABLE 3 DEPTH/TIME PROFILE

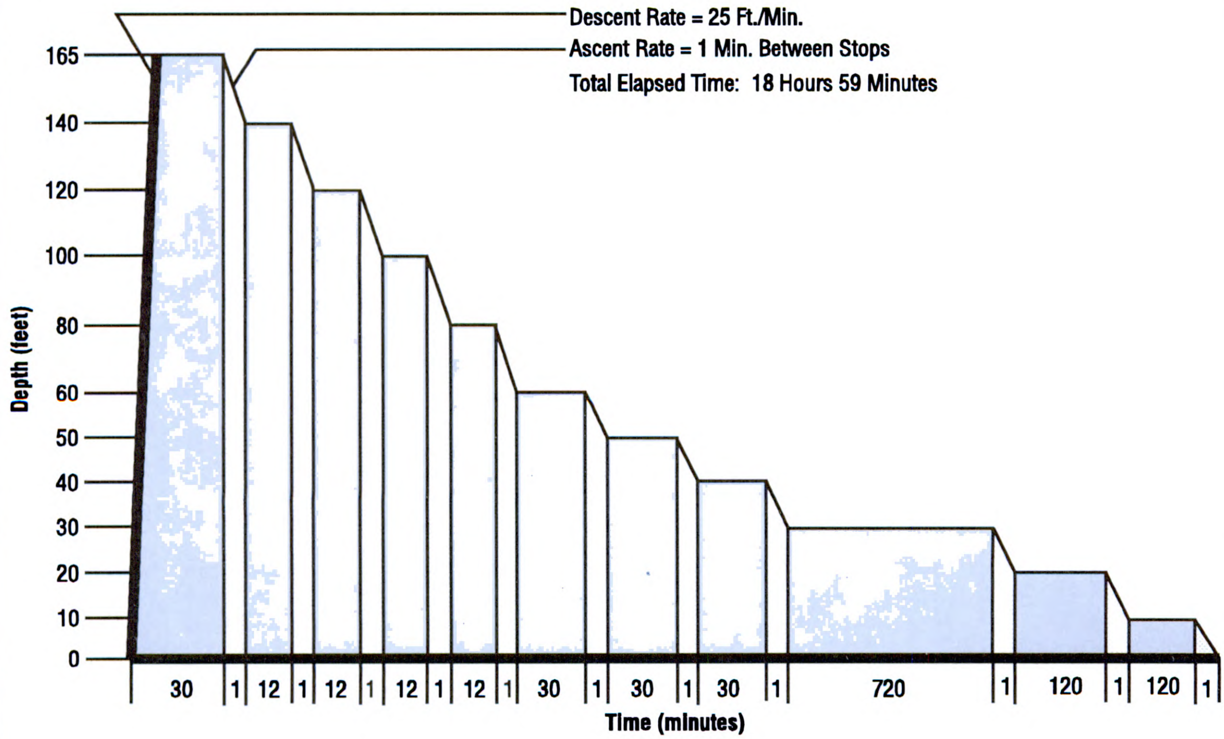


Figure 8-13. Air Treatment Table 3.

The Air Treatment Tables (1A, 2A, 3, and 4 using air) are used when no oxygen is available. They are not as effective as the Oxygen Treatment Tables. Note that Treatment Table 4 can be used with or without oxygen breathing.

8-15.3 Recompression Treatments When Oxygen Is Available. Use Oxygen Treatment Tables 5, 6, 6A, 4, or 7, according to the flowcharts in Figures 8-2 through 8-4. Additional guidelines for each treatment table are given below.

8-15.3.1 Treatment Table 5. Treatment Table 5 is used for Type I (pain only) symptoms when a complete neurological examination has revealed no abnormality. Treatment Table 5 may be used following asymptomatic omitted decompression of shallow surfacing (20 fsw or less). Treatment Table 5 is also used following asymptomatic omitted decompression of blowup (from deeper than 20 fsw) if the missed decompression is less than 30 minutes. Treatment Table 5 is used for asymptomatic divers who have exceeded surface interval limits following a Sur-D dive. After arrival at 60 fsw a neurological exam shall be performed (see Appendix H) to ensure that no overt neurological symptoms (e.g., weakness, numbness, incoordination) are present. If any abnormalities are found, the stricken diver should be treated using Treatment Table 6.

If the stricken diver is in Initial Evaluation Category B or C, a delay in treatment for up to 15 minutes after the recompression chamber is ready is permissible to wait for notified medical personnel to arrive. After medical personnel arrive, the delay may be extended an additional 15 minutes so that an adequate neurological examination can be performed. If obvious neurological symptoms occur at any time, the diver is then considered Category A and recompression to 60 feet in the recompression chamber on Treatment Table 6 must commence at once. Even if pain is the only symptom, do not delay recompression more than 30 minutes from the time the chamber is ready for treatment.

Treatment Table 6 is mandatory if (1) Type I pain is severe and immediate recompression must be instituted before a neurological examination can be performed, if (2) a complete neurological examination can not be performed, or if (3) any neurological symptom is present. These rules apply no matter how rapidly or completely the symptoms resolve once recompression begins.

If complete relief of Type I symptoms is not obtained within 10 minutes at 60 feet, Table 6 is required

Symptoms of musculoskeletal pain which have shown absolutely no change after the second oxygen breathing period at 60 feet may be due to orthopedic injury rather than decompression sickness. If, after review of the patient's history, the Diving Medical Officer feels that the pain can be related to specific orthopedic trauma or injury, Treatment Table 5 may be completed. If no Diving Medical Officer is on site, Treatment Table 6 shall be used. Note that once recompression to 60 feet is done, Treatment Table 5 will be used even if it was decided symptoms were probably not decompression sickness. Direct ascent to the surface is done only in emergencies.

If there is any doubt as to the presence of neurological or cardiorespiratory symptoms, Treatment Table 6 should be used. Treating Type II decompression sickness on Treatment Table 5 could result in recurrences and substantial residual damage.

8-15.3.2 Treatment Table 6. Treatment Table 6 is used for the treatment of Type II symptoms, arterial gas embolism responding to treatment at 60 feet, and Type I symptoms not showing complete relief within 10 minutes after arriving at 60 feet. Table 6 should be extended at 60 feet if residual symptoms, other than mild soreness around affected joints, persist after the third oxygen breathing period. If residual symptoms other than soreness persist at 30 feet, Table 6 should be extended at 30 feet.

Arterial gas embolism is also treated by initial compression to 60 fsw. If symptoms stabilize within the first oxygen breathing period, then treatment is continued using Treament Table 6. If during the first oxygen breathing period deterioration is noted, then compression to 165 feet should begin and Treatment Table 6A started. If a DMO is on scene or available for consultation, then treatment may continue at 60 feet upon his recommendation.

Treatment Table 6 is also used following blowup (from depths greater than 20 fsw) when the diver is asymptomatic but more than 30 minutes of decompression have been omitted, and for all symptomatic divers who blowup or surface with omitted decompression from 60 fsw or shallower.

8-15.3.3 Treatment Table 6A. Treatment Table 6A is used for the initial treatment of any neurological symptoms arising after a blowup from depths greater than 60 feet. It is also used for treatment of arterial gas embolism not responding to initial compression to 60 feet. In this case, Treatment Table 6A is followed when complete relief of symptoms is obtained within 30 minutes at 165 feet. Once ascent to 60 feet has been accomplished, the guidelines for Treatment Table 6 should be followed. Treatment Table 6A may be extended at 60 and/or 30 feet in the same manner as Treatment Table 6. In some cases, while complete relief was thought to have occurred at 165 feet, minor residual symptoms such as minor paresthesias or weakness may be found upon arrival at 60 feet once a thorough evaluation is completed. The extensions of Treatment Table 6A at 60 and 30 feet may be used to allow more time for these symptoms to resolve. Recurrence of symptoms which have disappeared completely at 165 feet, or occurrence of new symptoms, will require recompression in accordance with Figure 8-4.

In patients who improve at 165 feet but do not obtain complete relief within 30 minutes, an additional 90 minutes should be spent at 165 feet and the patient decompressed on Table 4. Some patients may show absolutely no improvement after 30 minutes at 165 feet. If treatment was initiated at promptly (less than four hours delay between symptom appearance and recompression), these patients should be kept at 165 feet for an additional 90 minutes and then decompressed on a Treatment Table 4. Patients whose initial treatment has been delayed four hours or more, and who show no improvement after 30 minutes at 165 feet, will probably not benefit from additional time at 165 feet. They should be decompressed according to Treatment Table 6A. In certain cases, however, a Diving Medical Officer may recommend a shift to Table 4.

If a shift from Treatment Table 6A to Treatment Table 4 is contemplated, a Diving Medical Officer should be consulted, if possible, before the shift is made.

8-15.3.4 Treatment Table 4. Treatment Table 4 is available for treatment of certain cases of arterial gas embolism and Type II decompression sickness at 165 feet, where deterioration is noted after initial recompression to 60 feet and/or it is felt deeper recompression is needed. In general, treatment cases which should be considered for Treatment Table 4 are those which have had treatment initiated promptly with no improvement and deterioration occurs at 60 feet. If more than a six to eight hour delay has occurred, prior to initiation of recompression, the patient probably will not benefit from further compression to 165 feet.In these cases, Treatment at 60 feet should be continued.

If deterioration is noted during ascent to 60 feet, treat as a recurrence of symptoms (Figure 8-4).

If possible, a Diving Medical Officer should be consulted, before committing the patient to Table 4. If a diver is put on Treatment Table 4, the full 120 mintutes should be spent at 165 feet unless operational or unforeseen medical considerations dictate earlier decompression.

If oxygen is available, the patient should begin oxygen breathing periods immediately upon arrival at the 60-foot stop. Breathing periods of 25 minutes on oxygen, interrupted by five minutes of air, are recommended because each cycle lasts 30 minutes. This simplifies timekeeping. Immediately upon arrival at 60 feet, a minimum of four oxygen breathing periods (for a total time of two hours) should be administered. After that, oxygen breathing should be administered to suit the patient's individual needs and operational conditions (Paragraph 8-15.4.1). Both the patient and tender must breathe oxygen for at least four hours (eight 25-minute oxygen, 5-minute air periods), beginning no later than two hours before ascent from 30 feet is begun. These oxygen breathing periods may be divided up as convenient, but at least two hours worth of oxygen breathing periods should be completed at 30 feet.

8-15.3.5 Treatment Table 7. Treatment Table 7 is considered a heroic measure for the treatment of non-responding severe gas embolism or life-threatening decompression sickness. Committing a patient to a Treatment Table 7 involves isolating the patient and having to minister to his medical needs in the recompression chamber for 48 hours or longer, and experienced medical and/or paramedical personnel should be on scene.

A Diving Medical Officer should be consulted, if possible, before shifting to a Treatment Table Seven, and careful consideration must be given to life support capability (Paragraph 8-15.5). In addition, it must be realized that the recompression facility will be committed for 48 hours or more.

Consultation with a Diving Medical Officer shall be established as soon as possible.

Indications - Treatment Table 7 is an extension at 60 feet of Treatment Tables 6, 6A, or 4 (or any other nonstandard treatment table). This means that considerable treatment has already been administered. Treatment Table 7 is not designed to treat all residual symptoms that do not improve at 60 feet and should never be used to treat residual pain. Treatment Table 7 should be used only when the severity of the symptoms are such that marked residual impairment or loss of life may result if the currently prescribed decompression from 60 feet is undertaken.

Examples of conditions which would necessitate staying at 60 feet on Treatment Table 7 are: continued complete paralysis of limbs, coma, and/or loss of spontaneous respiration. Treatment Table 7 would probably not be used for: numbness, tingling, decreased sensation to touch (collectively termed paresthesias), limb weakness (as long as the patient can actually move the limb against gravity), or bladder problems without limb paralysis. These latter symptoms often respond to additional daily hyperbaric treatments (Paragraph 8-16.2). If patients have been improving at 60 feet, are conscious, breathe on their own, and can move their extremities against gravity, generally they should not be put on Treatment Table 7 unless deterioration in their condition is noted during decompression from 60 feet.

Extremely ill patients suffering from Type II decompression sickness or arterial gas embolism, who have had significant delays in starting recompression therapy (six to eight hours), may continue to deteriorate at depth. In these types of cases, Treatment Table 7 should be initiated if deterioration is still occurring at 60 feet. Because judgements as to whether a particular patient's condition warrants Treatment Table 7 will be difficult to make, additional consultation from either NMRI or NEDU should be obtained (phone numbers are listed at the beginning of Section 8C).

Time at Depth - When using Treatment Table 7, a minimum of 12 hours should be spent at 60 feet, including time spent at 60 feet from Treatment Table 4, 6, or 6A. Severe Type II decompression sickness and/or arterial gas embolism cases may continue to deteriorate significantly over the first several hours. This should not be cause for premature changes in depth. Do not begin decompression from 60 feet for at least 12 hours. At completion of the 12-hour stay, the decision must be made whether to decompress or spend additional time at 60 feet. If no improvement was noted during the first 12 hours, benefit from additional time at 60 feet is unlikely and decompression should be started. If the patient is improving but significant residual symptoms remain (i.e., limb paralysis, abnormal or absent respirations), additional time at 60 feet may be warranted. While the actual time that can be spent at 60 feet is unlimited, the actual additional amount of time beyond 12 hours that should be spent can only be determined by a Diving Medical Officer (in consultation with on-site supervisory personnel), based on the patient's response to therapy and operational factors. When the patient has progressed to the point of consciousness, can breathe independently, and can move all extremities, decompression can be started and maintained as long as improvement continues. Solid evidence of continued benefit should be established for stays longer than 18 hours at 60 feet.

Decompression - When using Treatment Table 7, tenders breathe chamber atmosphere. Chamber oxygen should be kept above 19 percent (Paragraph 8-15.5.2) and carbon dioxide below 1.5 percent surface equivalent (sev) (11.4 mmHg, Paragraph 8-15.5.3). Decompression on Treatment Table 7 is begun with an upward excursion at time zero from 60 to 58 feet. Subsequent two-feet upward excursions are made at time intervals appropriate to the rate of decompression:

Depth	Rate	Time Interval
58-40 feet	3 ft/hr	40 min
40-20 feet	2 ft/hr	60 min
20-4 feet	1 ft/hr	120 min

Upon arrival at four feet, decompression should be stopped for four hours. At the end of four hours at four feet, decompress to the surface at one foot per minute. This procedure prevents inadvertent early surfacing.

The travel time between subsequent steps is considered as part of the time interval for the next shallower stop. The time intervals shown above begin when ascent to the next shallower stop has begun.

Oxygen Breathing - On a Treatment Table 7, patients should begin oxygen breathing periods as soon as possible at 60 feet. Oxygen breathing periods of 25 minutes on 100-percent oxygen, followed by five minutes breathing chamber atmosphere, should be used. Normally, four oxygen breathing periods are alternated with two hours of continuous air breathing. In conscious patients, this cycle should be continued until a minimum of eight oxygen breathing periods have been administered (previous 100-percent oxygen breathing periods may be counted against these eight periods). Beyond that, oxygen breathing periods should be continued as recommended by the Diving Medical Officer, as long as improvement is noted and the oxygen is tolerated by the patient. If oxygen breathing causes significant pain on inspiration, it should be discontinued unless it is felt significant benefit from oxygen breathing is being obtained. In unconscious patients, oxygen breathing should be stopped after a maximum of 24 oxygen breathing periods have been administered. The actual number and length of oxygen breathing periods should be adjusted by the Diving Medical Officer to suit the individual patient's clinical condition and response to oxygen toxicity (Paragraph 8-15.4.1).

Sleeping, Resting, and Eating - At least two tenders should be available when using a Treatment Table 7 and three may be necessary for severely ill patients. All tenders are not required to be in the chamber and they may be locked in and out as required following appropriate decompression tables. The patient may sleep anytime except when breathing oxygen below 30 feet. While asleep, the patient's pulse, respiration, and blood pressure should be monitored and recorded at intervals appropriate to the patient's condition. Food may be taken at any time and fluid intake should be maintained as outlined in Paragraph 8-15.5.4.

Ancillary Care - Patients on Treatment Table 7 requiring intravenous and/or drug therapy should have these administered in accordance with Paragraph 8-15.4.2.

Life Support - Before committing to a Treatment Table 7, the life support considerations in Paragraph 8-15.5 must be addressed. Do not commit to a Table 7 if the internal chamber temperature cannot be maintained at 85°F (29.4°C) or less (Paragraph 8-15.5.4).

Abort Procedures - In some cases, a Treatment Table 7 may have to be terminated early. If extenuating circumstances dictate early decompression, and less than 12 hours have elapsed since treatment was begun, decompression may be accomplished using the appropriate 60-foot Air Decompression Table as modified below. The 60-foot Air Decompression Tables may be used even if time was spent between 60 and 165 feet (e.g., on Table 4 or 6A), as long as at least three hours have elapsed since the last excursion below 60 feet. If less than three hours have elapsed, or if any time was spent below 165 feet, use the Air Decompression Table appropriate to the maximum depth attained during treatment. All stops and times in the Air Decompression Table should be followed, but oxygen breathing periods should be started for all chamber occupants as soon as a depth of 30 feet is reached. All chamber occupants should continue oxygen breathing periods of 25 minutes on 100-percent oxygen, followed by five minutes on air, until the total time breathing oxygen is one-half or more of the total decompression time.

If more than 12 hours have elapsed since treatment was begun, the decompression schedule of Treatment Table 7 must be used. In extreme emergencies, the abort recommendations (Paragraph 8-18) may be used if more than 12 hours have elapsed since beginning treatment.

8-15.3.6 Treatment Table 8. Treatment Table 8 is an adaptation of a Royal Navy Treatment Table 65 mainly for treating deep blowups (see Volume 2, Paragraph 11-4.10) when more than 60 minutes of decompression have been missed. However, upon the recommendation of a Diving Medical Officer, Table 8 can be used for recompression deeper than 165 feet (225 feet maximum) or to extend holds at depths between 165 and 60 feet. The Table 8 schedule from 60 feet is the same as Treatment Table 7. Guidelines for use of Table 8 are the same as for Table 4 or Table 7.

8-15.3.7 Delays in Leaving 60 Feet. The decision to recompress deeper than 60 feet and switch to a Table 6A or 4 when following the flowchart in Figure 8-3 must be made within 20 minutes of arrival at 60 feet. If more than 20 minutes was spent at 60 feet before deeper recompression was instituted then Table 4 should be followed back to 60 feet and Table 7 followed from 60 feet to the surface.

8-15.3.8 Additional Recompression Below 60 Feet. Once committed to a Table 7, the time spent at 60 feet is unlimited. However, occasions may arise where the DMO deems that deeper recompression may be of benefit even after some time has been spent at 60 feet. On the advice of the DMO, deeper recompression to depths down to 165 feet may be done. If no benefit is observed within 30 minutes of leaving 60 feet, direct ascent back to 60 feet at 20 feet/minute may be done. If a benefit is observed, then at least two hours shall be spent at depth and Table 4 followed back to 60 feet. If a longer time is needed, then the stop may be extended up to the maximum time at initial treatment depth for Table 8, and Table 8 followed back to 60 feet.

No matter what the duration at the recompression below 60 feet, at least 12 hours must be spent at 60 feet and then Table 7 followed to the surface. Additional recompression below 60 feet in these cases should not be undertaken unless adequate life support capability is available.

8-15.4 Tending the Patient. When conducting a recompression treatment, at least one qualified tender shall be inside the chamber. The inside tender must be familiar with all treatment procedures and the signs, symptoms, and treatment of all diving related disorders.

If it is known before the treatment begins that involved medical aid must be administered to the patient, or if the patient is suspected of suffering from arterial gas embolism, a Diving Medical Technician or Diving Medical Officer should accompany the patient inside the chamber. However, recompression treatment should not be delayed to comply with this requirement. If the chamber is sufficiently large, a second tender may also enter the chamber to assist during treatment.

If only one Diving Medical Officer is present, the Medical Officer's time in the chamber should be kept to a minimum because effectiveness in directing the treatment is greatly diminished when inside the chamber. If periods in the chamber are necessary, visits should be kept within no-decompression limits (if possible).

Inside the chamber, the tender ensures that the patient is lying down and positioned to permit free blood circulation to all extremities. The tender closes and secures the inner lock door and pressurization begins at 25 fpm.

Descent rates may have to be decreased as necessary to allow the patient to equalize; however, attaining treatment depth as fast as possible for a suspected arterial gas embolism patient is vital.

During the early phases of treatment, the inside tender must monitor the patient constantly for signs of relief. Drugs that mask signs of the illness should not be given. Observation of these signs is the principal method of diagnosing the patient's illness. Furthermore, the depth and time of their relief designates the treatment table to be used. Once the appropriate treatment has been committed to, it may only be altered by a Diving Medical Officer. Other responsibilities of the inside tender are:

(1) Releasing the door latches (dogs) after a seal is made.

(2) Communications with outside personnel.

(3) Providing first aid as required by the patient.

(4) Administering oxygen to the patient.

(5) Providing normal assistance to the patient as required.

(6) Ensuring that sound attenuators for ear protection are worn during compression and ventilation portions of recompression treatments.

8-15.4.1 Oxygen Breathing and Toxicity During Treatments. During prolonged treatments on Treatment Tables 4,7 or 8 pulmonary oxygen toxicity may develop. Acute CNS oxygen toxicity may develop on any oxygen treatment table. Refer to Paragraph 8-2.4 for further discussion of oxygen toxicity during in-water dives.

Central Nervous System Oxygen Toxicity - When employing the oxygen treatment tables, tenders must be particularly alert for the early warning signs of CNS oxygen toxicity. They can be remembered readily by using the acronym VENTID (Vision, Ears, Nausea, Twitching, Irritability, Dizziness). For additional information, refer to Paragraph 8-2.4.

At the first sign of CNS oxygen toxicity, the patient should be removed from oxygen and allowed to breathe chamber air. Fifteen minutes after all symptoms have subsided, oxygen breathing may be restarted. If symptoms of CNS oxygen toxicity develop again, interrupt oxygen breathing for another 15 minutes. If CNS oxygen toxicity develops a third time, discontinue oxygen and consult with the Diving Medical Officer who will have to decide on future oxygen administration and on whether or not decompression should be attempted or continued or whether deeper recompression is needed.

CNS oxygen toxicity is unlikely in resting individuals at depths of 50 feet or shallower, and very unlikely at 30 feet or shallower, no matter what the level of activity. However, patients with severe Type II decompression sickness or arterial gas embolism symptoms may be abnormally sensitive to CNS oxygen toxicity. Convulsions unrelated to oxygen toxicity may also occur and may be impossible to distinguish from oxygen seizures. Figures 8-5, 8-6, and 8-7 explain how to handle interruptions in oxygen breathing on Treatment Tables 5, 6, and 6A. Treatment Tables 4, 7 and 8 do not require compensatory lengthening or alteration if oxygen breathing must be interrupted. If an oxygen convulsion occurs, discontinue oxygen and keep the patient from harm. The patient's head should be tilted back gently and the jaw prevented from falling backward and obstructing the airway. Insertion of an airway device or bite block is unnecessary while the patient is convulsing; it is not only difficult but may cause harm if attempted.

Pulmonary Oxygen Toxicity - Pulmonary oxygen toxicity is unlikely to develop on Treatment Tables 5, 6, or 6A. On Treatment Tables 4, 7 or 8 the large amounts of oxygen that may have to be administered may result in end-inspiratory discomfort, progressing to substernal burning and severe pain on inspiration. Substernal burning is normally cause for discontinuing oxygen breathing in patients who are responding well to treatment. However, if a significant neurological deficit remains and improvement is continuing (or if deterioration occurs when oxygen breathing is interrupted), oxygen breathing should be continued as long as considered beneficial or until pain limits inspiration. If oxygen breathing must be continued beyond the period of substernal burning, or if the two-hour air breaks on Treatment Tables 4, 7 or 8 cannot be used because of deterioration upon the discontinuance of oxygen, the oxygen breathing periods should be changed to 20 minutes on oxygen, followed by 10 minutes breathing chamber air. The Diving Medical Officer may tailor the above guidelines to suit individual patient response to treatment.

8-15.4.2 Ancillary Care and Adjunctive Treatments. Drug therapy should be administered only after consultation with a Diving Medical Officer. Chamber tenders must be adequately trained and be capable of administering prescribed treatments. Always ensure patients are adequately hydrated. Fully conscious patients may be given fluid by mouth to maintain adequate hydration. One to two liters of water , juice or non-carbonated drink, over the course of a Table 5 or 6, is usually sufficient. Patients with Type II symptoms, or symptoms of arterial gas embolism, should be considered for I.V. fluids. Stuporous or unconscious patients should always be given I.V. fluids, using large gauge plastic catheters such as Medicut or Angiocath. If trained personnel are present, an I.V. should be started as soon as possible and kept dripping at a rate of 75 to 100 cc/hour, using isotonic fluids (Lactated Ringer's Solution, Normal Saline) until specific instructions regarding the rate and type of fluid administration are given by qualified medical personnel. Avoid solutions containig only Dextrose (D5W) as they may contribute to edema as the sugar is metabolized. In some cases, the bladder may be paralyzed. The victim's ability to void should be assessed as soon as possible. If the patient cannot empty a full bladder then a urinary catheter should be inserted as soon as possible by trained personnel. Always inflate catheter balloons with liquid, ***not air***. Adequate fluid is being given when urine output is above 35cc/hour.

There is no consensus on the usefulness of adjunctive therapy, other than I.V. fluids. The most frequently recommended adjunctive therapy is dexamethasone (Decadron) based on the following reasons:

- Decreases tissue swelling (edema)
- Decreases tissue inflammation
- Decreases leaking of blood vessels
- Helps prevent histamine release

General opinion is that spinal cord and brain edema cause many late-appearing neurological problems in DCS/AGE. In this case steroids may be useful but their efficiency has not been proven. They do not become effective, however, for four to six hours after intravenous introduction. Therefore, administer these drugs early in the treatment. Do not delay recompression while preparing these drugs. The initial recommended dose is 10 mgm I.V. for cerebal edema. Some clinicians have recommended doses as high as 100 mgm I.V. The initial dose is followed by 4 mgm every 6 hours which may be given I.V., I.M. or by mouth. Steroids should not be used for more then 72 hours on this schedule.

Steroids or other drugs can be used only upon the prescription by and under supervision of a Diving Medical Officer.

8-15.4.3 Sleeping and Eating. The only time the patient should be kept awake during recompression treatments is during oxygen breathing periods at depths greater than 30 feet. Travel between decompression stops on Treatment Tables 4, 7 and 8 is not a contraindication to sleeping. While asleep, vital signs (pulse, respiratory rate, blood pressure) should be monitored as the patient's condition dictates. Any significant change would be reason to arouse the patient and ascertain the cause. Food may be taken by chamber occupants at any time. Adequate fluid intake should be maintained as discussed in Paragraph 8-15.5.4.

8-15.5 Recompression Chamber Life Support Considerations. The short treatment tables (Oxygen Treatment Tables 5, 6, 6A; Air Treatment Tables 1A and 2A) can be accomplished easily without significant strain on either the recompression chamber facility or support crew. The long treatment tables (Tables 3, 4, and 7) will require long periods of decompression and may tax both personnel and hardware severely.

8-15.5.1 Manning Requirements. The minimum team for conducting any recompression operation consists of two individuals:

(1) **Diving Supervisor -** in complete charge at the scene of the operation. Responsible for the operation of gas supplies, ventilation, pressurization, exhaust of the cham-

ber, keeping individual and overall times on the operation, logging progress and communicating with personnel inside the chamber.

(2) **Inside Tender** - familiar with the diagnosis and treatment of diving-related sicknesses.

The optimum team for conducting recompression operations consists of four individuals:

(1) **Diving Supervisor** - in complete charge at the scene of the operation.

(2) **Outside Tender #1** - responsible for the operation of the gas supplies, ventilation, pressurization, and exhaust of the chamber.

(3) **Outside Tender #2** - responsible for keeping individuals' and overall times on the operation, logging progress as directed by the Diving Supervisor, and communicating with personnel inside the chamber.

(4) **Inside Tender** - familiar with the diagnosis and treatment of diving-related sicknesses.

If the patient has symptoms of serious decompression sickness or arterial gas embolism, the team will require additional personnel. If the treatment is prolonged, a second team may have to relieve the first team. Patients with serious decompression sickness and gas embolism would initially be accompanied inside the chamber by a Diving Medical Technician or Diving Medical Officer if possible. However, treatment should not be delayed to comply with this recommendation.

A Diving Medical Officer should be consulted, if at all possible, before committing the patient to a Treatment Table 4, 7 or 8. The Diving Medical Officer may be on scene or in communication with the Diving Supervisor.

8-15.5.2 Oxygen Control. Usually, all treatment schedules listed in this chapter are performed with a chamber atmosphere of air. In order to accomplish safe decompression, the oxygen percentage should not be allowed to fall below 19 percent. Oxygen may be added to the chamber by ventilating with air or by bleeding in oxygen from an oxygen breathing system. If a portable oxygen analyzer is available, this can be used to determine the adequacy of ventilation and/or addition of oxygen. If no oxygen analyzer is available, ventilation of the chamber in accordance with Paragraph 8-15.5.5 will ensure adequate oxygenation. Chamber oxygen percentages as high as 25 percent are permitted. If the chamber is equipped with a life support system so that ventilation is not required and an oxygen analyzer is available, the oxygen level should be maintained between 20 percent and 25 percent by bleeding oxygen into the chamber. If chamber oxygen goes above 25 percent, ventilation with air should be substituted to bring the oxygen percentage down.

8-15.5.3 Carbon Dioxide Control.
Ventilation of the chamber in accordance with Paragraph 8-15.5.5 will ensure that carbon dioxide produced metabolically does not cause the chamber carbon dioxide level to exceed 1.5 percent SEV (11.4 mmHg). Hand sample detector tube analyzers such as the Draeger hand pump (National Stock Number 1H6665-00-710-7815), with carbon dioxide detector tubes (National Stock Number 1H6665-00-769-0945), can be used inside the chamber to verify the level of carbon dioxide. Follow the instructions for sampling at one ata. Since the detector draws an actual volume of gas, more gas molecules will be drawn through the detector tube at depth. This will automatically correct the reading on the tube for depth and the tube will read directly in partial pressure. As an example, if the detector tube reads 1.0 percent inside the cham-

ber at depth, this means that the partial pressure of carbon dioxide inside the chamber will be 1.0 percent SEV (7.60 mmHg), the same partial pressure which would cause the tube to read 1.0 percent at 1 ata.

Chamber carbon dioxide can be monitored with electronic chamber carbon dioxide monitors also. These monitors generally read CO_2 percentage once chamber air has been exhausted to the surface. The CO_2 percent reading at the surface 1 ata must be corrected for depth. In order to keep chamber CO_2 below 1.5 percent SEV (11.4 mmHg) the surface CO_2 monitor values should remain below 0.8 percent with chamber depth at 30 feet, 0.54 percent with chamber depth at 60 feet, and 0.25 percent with the chamber at 165 feet.

If the chamber is equipped with a carbon dioxide scrubber, the absorbent should be changed when the partial pressure of carbon dioxide in the chamber reaches 1.5 percent SEV (11.4 mmHg). If absorbent cannot be changed, supplemental chamber ventilation will be required to maintain chamber CO_2 at acceptable levels. Authorized chamber carbon dioxide scrubbers are included in NAVSEA Instruction 10560.2 (series). With multiple or working chamber occupants, supplemental ventilation may be necessary to maintain chamber CO_2 at acceptable levels.

8-15.5.4 Temperature Control and Patient Hydration. If possible, internal chamber temperature should be maintained at a level comfortable to the occupants. Cooling can usually be accomplished by chamber ventilation in accordance with Paragraph 8-15.5.5. If the chamber is equipped with a heater/chiller unit, temperature control can usually be maintained for chamber occupant comfort under any external environmental conditions. Usually, recompression chambers will become hot, and must be cooled continuously. Chambers should always be shaded from direct sunlight. The maximum durations for chamber occupants will depend on the internal chamber temperature as listed in Table 8-4. Never commit to a treatment table that will expose the chamber occupants to greater temperature/time combinations than listed in Table 8-4 unless qualified medical personnel who can evaluate the trade off between the projected heat stress and the anticipated treatment benefit are consulted. A chamber temperature below 85°F (29.4°C) is always desirable, no matter which treatment table is used.

Table 8-4. Maximum Permissible Recompression Chamber Exposure Times at Various Temperatures.

Internal Temperature	Maximum Tolerance Time	Permissible Treatment Tables
Over 104°F (40°C)	Intolerable	No Treatments
94-104°F (34.4 -40°C)	2 hours	Table 5
85-94°F (29.4-34.4°C)	6 hours	Tables 5, 6, 6A, 1A
Under 85°F (29.4°C)	Unlimited	All

NOTE

Internal chamber temperature can be kept considerably below ambient by venting or by using an installed chiller unit. Internal chamber temperature can be measured using electronic, bimetallic, alcohol, or liquid crystal thermometers. **Never use a mercury thermometer in or around hyperbaric chambers.** Since chamber ventilation will prodduce temperature swings during ventilation, the above limits should be used as averages when controlling temperature by ventilation. **Always shade chamber from direct sunlight.**

Successful treatment of decompression sickness depends upon adequate hydration. Thirst is an unreliable indicator of the water intake necessary to compensate for heavy sweating, and isolation of the patient within the recompression chamber makes it difficult to assess his overall fluid balance. Failure to completely replace water lost by sweating may lead to elevation of body temperature and dehydration. Overheating of the diver initially causes generalized symptoms that may be confused with symptoms caused by the diving accident. They may not be recognized as being related to the effects of heat. Symptoms of heat exhaustion may include headache, dizziness, fainting, vomiting, and profound weakness. The skin is usually moist and clammy, the pulse weak and rapid. Progression of symptoms with failure of temperature regulation mechanism results in heat stroke, which is characterized by increased body temperature, confusion, incoordination, delirium, and the presence of hot, dry, flushed skin with little or no sweating. Heat stroke is a medical emergency that requires prompt and aggressive treatment (cooling with towels soaked in ice water and fluid replacement). By providing adequate hydration and following the temperature/time guidelines in Table 8-4, heat exhaustion and heat stroke can be avoided. If the chamber temperature is above 85°F (29.4°C), chamber occupants should drink approximately one quart of water hourly; below 85°F they should drink an average of one pint hourly. An average urine output of at least one ounce per hour (30 ml) in patients and tenders is a good indication of adequate hydration.

8-15.5.5 Chamber Ventilation. For chambers without carbon dioxide scrubbers or oxygen addition systems, ventilation is the usual means of controlling oxygen level, carbon dioxide level, and temperature. In order to control chamber carbon dioxide levels, a ventilation rate of two acfm for each resting occupant and four acfm for each active occupant should be used. Chamber ventilation procedures are presented in Appendix D. These procedures are designed to assure that the effective concentration of carbon dioxide will not exceed 1.5 percent SEV (11.4 mmHg) and that, when oxygen is being used, the percentage of oxygen in the chamber will not exceed 25 percent.

8-15.5.6 Access to Chamber Occupants. Recompression treatments usually require access to occupants for passing in items such as food, water, and drugs, and passing out such items as urine, excrement, and trash. Never attempt a treatment longer than a Treatment Table 6 unless there is access to inside occupants. When doing a Treatment Table 4 or 7, a double lock chamber is ***mandatory*** because additional personnel may have to be locked in and out during treatment.

8-15.5.7 Inside Tenders. For Type I decompression sickness, one qualified inside tender is required. For Type II decompression sickness, medical personnel may have to be locked into the chamber as the patient's condition dictates. If one Diving Medical Officer is on site, the Medical Officer should lock in and out as the patient's condition dictates, but should not commit to the entire treatment unless absolutely necessary. Once committed to remain in the chamber, the Diving Medical Officer will not be able to aid the treatment as well and consultation with other medical personnel becomes more difficult.

Oxygen Breathing - During treatments, all chamber occupants may breathe 100-percent oxygen at depths of 30 feet or shallower without locking in additional personnel. Tenders should not fasten the oxygen masks to their heads, but should hold them on their faces. Deeper than 30 feet, at least one chamber occupant must breathe air.

On Table 4, tenders are required to breathe oxygen for two hours before leaving 30 feet and for two additional hours during decompression from 30 feet to the surface.

On Table 6A, tenders should breathe 100-percent oxygen during the final 60 minutes at 30 feet and during ascent to the surface. If the tender has had a previous hyperbaric exposure within 12 hours, the tender breathes oxygen for an additional 60 minutes at 30 feet.

For an unmodified Table 6 or when there has been only a single extension at 60 or 30 feet, the tender breathes 100-percent oxygen for the final 30 minutes at 30 feet and during ascent to the surface. If there has been more than one extention, oxygen breathing is done for the entire 60 minute period at 30 feet and during ascent to the surface. If the tender has had a hyperbaric exposure within the past 12 hours, then an additional 60 minute oxygen period at 30 feet is added.

On Table 5, oxygen should be breathed by the tender during the 20-minute oxygen breathing period at 30 feet and during the final 30-minute ascent to the surface, for all Table 5 treatments.

Tending Frequency - Normally, tenders should allow a surface interval of at least 12 hours between consecutive treatments on Tables 1A, 2A, 3, 5, 6, and 6A, and at least 48 hours between consecutive treatments on Tables 4, 7 and 8. If necessary, however, tenders may repeat Treatment Tables 5, 6, or 6A within this 12-hour surface interval if oxygen is breathed at 30 feet and shallower as outlined above. Minimum surface intervals for Tables 1A, 2A, 3, 4, and 7 must be strictly observed.

8-15.6 Loss of Oxygen During Treatment. Loss of oxygen breathing capability during oxygen treatments is a rare occurrence. However, should this occur, the following should be done:

If repair can be effected within 15 minutes:

- Maintain depth until repair completed
- After O_2 is restored, resume treatment at point of interruption for Table 6 or 6A. For Table 5 shift to Table 6 at 30 fsw.

If repair can be effected after 15 minutes but before two hours:

- Maintain depth until repair completed
- After O_2 is restored:
  - If original table was Table 5, 6 or 6A complete treatment on Table 6 schedule with maximum number of O_2 extentions.

If Table 4, 7 or 8 is being used, no compensation in decompression is needed if O_2 lost. If decompression must be stopped because of worsening symptoms in the affected diver, then stop decompression. When oxygen is restored, continue treatment from where it was stopped.

If O_2 breathing cannot be restored in two hours:

- Symptoms still present:
  - Switch to Table 7 at current depth for decompression if 60 fsw or shallower.
  - Switch to Table 8 at current depth for decompression if deeper than 60 fsw.
  - If an increase in treatment depth deeper then 60 feet is needed, use Table 8.
- No symptoms present:
  - Depth 100 fsw or deeper; shift to Table 4 at current depth.
  - Depth less than 100 fsw but more than 60 feet, switch to Table 2A at current depth.

- Depth 60 fsw or less, switch to Table 1A at current depth.

- Treatment was for asymptomatic missed decompression:

  - Depth greater than 100 fsw, switch to Table 2A at current depth.

  - Depth 100 fsw or less, switch to Table 1A at current depth.

8-15.7 Use of High O_2 Nitrox Mixes. High oxygen nitrox mixtures may be administered during treatment at depths deeper than 60 fsw. Standard mixes are 50/50 nitrox or 32.5/67.5 nitrox mixtures. The mixture to be used is determined by the Diving Medical Officer when ordered or mixed, the tolerance must be ± 1%. The oxygen must meet MIL-O-27210 and the nitrogen must meet FED SPEC BB-N-411 Type I Class One Grade A.

8-16 POST-TREATMENT CONSIDERATIONS

Tenders on Tables 5, 6, 6A, 1A, 2A, or 3 should have a minimum of a 12-hour surface interval before no-decompression diving, and a minimum of a 24-hour surface interval before dives requiring decompression stops. Tenders on Tables 4, 7 and 8 should have a minimum of a 48-hour surface interval prior to diving.

After a treatment, patients treated on a Treatment Table 5 should remain at the recompression chamber facility for two hours. Patients who have been treated for Type II decompression sickness or who required a Treatment Table 6 for Type I symptoms and have had complete relief should remain at the recompression chamber facility for six hours. These times may be shortened upon the recommendation of a Diving Medical Officer, provided the patient will be with personnel who are experienced at recognizing recurrence of symptoms and can return to the recompression facility within 30 minutes. All patients should remain within 60 minutes of a recompression facility for 24 hours and should not be left alone during that period.

Patients with residual symptoms should be transferred to appropriate medical facilities as directed by qualified medical personnel. If ambulatory patients are sent home, they should always be accompanied by someone familiar with their condition who can return them to the recompression facility should the need arise. Patients completing treatment do not have to remain in the vicinity of the chamber if the Diving Medical Officer feels that transferring them to a medical facility immediately is in their best interest.

After completing treatments, inside tenders should remain in the vicinity of the recompression chamber for one hour. If they were tending for Treatment Table 4, 7 or 8, inside tenders should also remain within 60 minutes of a recompression facility for 24 hours.

8-16.1 Flying After Treatments. Patients with Type I symptoms who have had complete resolution of all symptoms can fly 24 hours after surfacing. Patients with Type II symptoms, who have had complete resolution, should not fly for 48 hours. Patients surfacing from a Treatment Table 4, 7 or 8 should not fly for 72 hours. Patients with residual symptoms should not fly for at least 72 hours after their last treatment, and only with the concurrence of a Diving Medical Officer.

Some patients will require air evacuation to another treatment or medical facility immediately after surfacing from a treatment. They will not meet surface interval requirements as described above. Such evacuation is done only on the recommendation of a Diving Medical Officer. Aircraft pressurized to one ata should be used if possible, or unpressurized aircraft flown as low as safely possible (no more than 1,000 feet is preferable). Have the patient breathe 100-percent oxygen during transport, if available.

Tenders on Tables 5, 6, 6A, 1A, 2A, or 3 should have a 12-hour surface interval before flying. Tenders on tables 4, 7 and 8 should not fly for 48 hours.

8-16.2 Treatment of Residual Symptoms. After completion of the initial recompression treatment, and after a surface interval sufficient to allow complete medical evaluation, additional recompression treatments may be instituted as prescribed by a Diving Medical Officer. For persistent Type II symptoms, daily treatment on Table 6 is preferred, but twice-daily treatments on Table 5 may also be used. Patients surfacing from Treatment Table 4, 7 or 8 may have severe pulmonary oxygen toxicity and may find breathing 100-percent oxygen at 60 feet uncomfortable. In these cases, daily treatments at 30 feet can be used. These treatments should be performed as prescribed by a Diving Medical Officer. As many oxygen breathing periods (25 minutes on oxygen followed by 5 minutes on air) should be administered as can be tolerated by the patient. Ascent to the surface is at one foot per minute. Three to four hours at 30 feet is a practical maximum bottom time. As tolerance to oxygen improves, Treatment Table 5 should be tried and, eventually Treatment Table 6, if indicated. Treatments should not be administered on a daily basis for more than five days without a break of at least one day. These guidelines may have to be modified by the Diving Medical Officer to suit individual patient circumstances and tolerance to oxygen.

Additional recompression treatments are indicated as long as they are prescribed by a Diving Medical Officer. In treating residual symptoms, no response to recompression may occur on the first one or two treatments. In these cases, the Diving Medical Officer is the best judge as to the number of treatments. Consultation with NMRI or NEDU may be appropriate (phone numbers are listed at the beginning of Section 8C). As the delay time between completion of initial treatment and the beginning of follow-up hyperbaric treatments increases, the probability of benefit from additional treatments decreases. However, improvement has been noted in patients who have had delay times of up to one week. Therefore, a long delay is not necessarily a reason to preclude follow-up treatments. Once residual symptoms respond to additional recompression treatments, such treatments should be continued until no further benefit is noted. In general, treatment may be discontinued if there is no further sustained improvement on two consecutive treatments.

8-16.3 Returning to Diving after Treatment. Divers who meet all of the criteria for treatment using Treatment Table 5, as outlined in Paragraph 8-15.3.1, and who have had complete relief, may return to normal diving activity 48 hours after surfacing from the Treatment Table 5. If there is any doubt about the presence or absence of Type II symptoms, the diver should be examined by a Diving Medical Officer before resumption of diving.

Upon the recommendation of a Diving Medical Officer, divers who have had Type I symptoms requiring a Treatment Table 6 and who have had complete resolution of symptoms may resume normal diving activity on the seventh day following treatment.

Divers whose only Type II symptoms were patchy peripheral numbness, tingling and/or decreased sensation (collectively called patchy peripheral paresthesia), that resolved competely by the second oxygen breathing period at 60 feet, may resume normal diving activity 14 days following treatment, upon recommendation of a Diving Medical Officer.

Divers who had symptoms of arterial gas embolism or who have had any cardiorespiratory or neurological involvement other than patchy peripheral paresthesia described above should not dive for at least four weeks and should resume diving only upon the recommendation of a Diving Medical Officer.

A diver having cardiorespiratory and/or CNS symptoms severe enough to warrant Treatment Table 4 or 7 should not dive for a minimum of three months, and not until a thorough review of his case by a Diving Medical Officer has established that return to normal diving activity can be accomplished safely.

8-17 NON-STANDARD TREATMENTS

The treatment recommendations presented in this chapter should be followed as closely as possible unless it becomes evident that they are not working. Only a Diving Medical Officer may then recommend changes to treatment protocols or use treatment techniques other than those described in this chapter. The standard treatment procedures in this chapter should be considered minimum treatments. Treatment procedures should never be shortened unless emergency situations arise which require chamber occupants to leave the chamber early.

8-17.1 Treatment of the Unconscious, Pulseless Diver. An unconscious diver without a pulse may be suffering from shock or cardiac arrest. Cardiac arrest (ventricular fibrillation) is a theoretical possibility in divers suffering from arterial gas embolism. It can also result from near drowning or electric shock. If a cardiac monitor and personnel trained in Advanced Cardiac Life Support (ACLS) are available, a stricken diver's electrocardiograph (EKG) should be monitored. If cardiac arrest is diagnosed, it should be treated appropriately prior to initiating recompression. If an EKG shows that cardiac arrest has not occurred, the appropriate recompression treatment should be started immediately.

If a cardiac monitor is not available and pulse is not detectable, a stricken diver may require ACLS when equipment and personnel become available. In such cases, a stricken diver should be recompressed to a depth of 60 fsw, while conducting BCLS. Do not go deeper than 60 fsw unless the pulse returns or a Diving Medical Officer has been consulted. Should a stricken diver remain unconscious with no detectable pulse and ACLS equipment and personnel become available, an attempt should then be made to verify if cardiac arrest has occurred.

Once cardiac arrest has been confirmed, appropriate ACLS procedures should be initiated. Recompression treatment should begin once cardiac arrest has been reversed. Specific procedures for combining ACLS with recompression treatment are not available and determining the appropriate treatment can only be done by personnel trained in diving medicine and ACLS. If a stricken diver does not respond to ACLS within 10 minutes, recompression treatment should be considered in order to determine if this will restore cardiac function. Consultation with NMRI and NEDU should be made as quickly as possible in these situations.

8-18 RECOMPRESSION TREATMENT ABORT PROCEDURES

Once recompression therapy is started, it should be completed according to the procedures in this chapter unless the diver being treated dies or unless continuing the treatment would place the chamber occupants in mortal danger.

If it appears that the diver being treated has died, qualified medical personnel must confirm the death before the treatment is aborted. If this is done, then the tenders may be decompressed by completing the treatment table, or by following the air decompression schedule (as modified below) for the total time since treatment began and the maximum depth attained. The shortest procedure should be used. The exception is Treatment Table 7. The appropriate abort procedure for Table 7 is discussed in Paragraph 8-15.3.5.

The air decompression schedule used in recompression treatment aborts is modified by having all chamber occupants begin breathing oxygen as soon as a depth of 30 feet or shallower is reached. Oxygen breathing periods of 25 minutes on oxygen, followed by five minutes on air, are continued until the total time on oxygen is one-half or more of the total decompression time. This procedure may be used even if gases other than air (i.e., nitrogen-oxygen or helium-oxygen mixtures) were breathed during treatment. Upon surfacing, chamber occupants are treated as if they had surfaced from a normal dive.

Impending natural disasters or mechanical failures may require aborting treatments. For instance, the ship on which the chamber is located may be in imminent danger of sinking, or a fire or explosion may have severely damaged the chamber system to such an extent that completing the treatment is impossible. In these cases, the abort procedure described above could be used for all chamber occupants (including the stricken diver) if time is available. If time is not available, the following may be done:

(1) If deeper than 60 feet, go immediately to 60 feet.

(2) Once the chamber is 60 feet or shallower, put all chamber occupants on continous 100-percent oxygen.

(3) Follow as much of the air decompression schedule (for maximum depth and total time) as possible, breathing 100-percent oxygen continuously.

(4) When no more time is available, bring all chamber occupants to the surface (try not to exceed 10 feet per minute) and keep them on 100-percent oxygen during evacuation, if possible.

(5) Immediately evacuate all chamber occupants to the nearest recompression facility and treat according to Figure 8-2. If no symptoms occurred after the treatment was aborted, follow a Treatment Table 6.

8-19 EMERGENCY MEDICAL EQUIPMENT

Every diving activity must maintain emergency medical equipment that will be available immediately for use at the scene of a diving accident. This equipment is to be in addition to any medical supplies maintained in a medical treatment facility, and must be kept in a kit small enough to carry into the chamber, or in a locker in the immediate vicinity of the chamber.

Because some sterile items may become contaminated as a result of a hyperbaric exposure, it is desirable to have a primary kit for immediate use inside the chamber and a secondary kit from which items which may become contaminated can be locked into the chamber only as needed. The lists of contents presented here are not meant to be restrictive but are considered minimum requirements. Additional items may be added to suit local medical preferences.

8-19.1 Emergency Kits. The Primary Emergency Kit is described in Table 8-5; the Secondary Emergency Kit is described in Table 8-6.

The primary emergency kit contains diagnostic and therapeutic equipment that is available immediately when required. This kit will be inside the chamber during all treatments.

The secondary emergency kit contains equipment and medicine that does not need to be available immediately, but can be locked-in when required. This kit will be stored in the vicinity of the chamber.

Only commands having recompression chambers with a medical officer attached shall maintain a portable monitor-defibrillator and those drugs listed with an asterisk (*). These drugs need to be in sufficient quantities to support an event requiring Advanced Cardiac Life Support. These drugs/equipment are not required to be in every dive kit when multiple chambers/kits are present in a single command.

8-19.2 Use of Emergency Kits. Unless adequately sealed against increased atmospheric pressure, sterile supplies should be resterilized after each pressure exposure, or, if not exposed, at six-month intervals. Drugs must be replaced when their expiration date is reached. Not all drug ampules will withstand pressure. Stoppered multidose vials should be vented with a needle during pressurization and then discarded if not used.

Because the available facilities may differ on board ship, at land-based diving installations, and at diver training or experimental units, the responsible Diving Medical Officer or Diving Medical Technician 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. Each kit is to contain a list of contents. Each time the kit is opened, it must be inventoried and each item checked for proper working order and then resterilized. Sterile supplies are to be provided in duplicate so that one set can be autoclaved while the other resides in the kit. The kits on-hand are inventoried, unopened, at four-month intervals. Normally, use of the emergency kit is to be restricted to the medical personnel. Concise instructions for administrating each drug are to be provided in the kit along with current American Heart Association Advanced Cardiac Life Support Protocols. In untrained hands, many of the items can be dangerous. Remember that as in all treatments **YOUR FIRST DUTY IS NOT TO DO HARM.**

Table 8-5. Primary Emergency Kit.

Diagnostic Equipment

- Flashlight
- Stethoscope
- Otoscope (Ophthalmoscope)
- Sphygmomanometer (Aneroid type only, case vented for hyperbaric use)
- Reflex hammer
- Tuning Fork (128 cps)
- Sterile safety pins or swab sticks which can be broken for sensory testing
- Tongue depressors

Emergency Treatment Equipment and Medications

- Oropharyngeal airways (#4 and #5 Geudel)
- Self-Inflating Bag-Mask ventilator with medium adult mask
  NOTE: Some of these units do not have sufficient bag volume to provide adequate ventilation. Use a Laerdal Resusci Folding Bag II (Adult) or equivalent.
- Foot-Powered or battery-powered suction unit
- Nonflexible plastic suction tips (Yankauer Suction Tip)
- Large bore needle and catheter (12 or 14 gauge) for cricothyrotomy or relief of tension pneumothorax
- Throcar Thoracic Suction Catheter (10F and 24F) or McSwain Dart
- Small Penrose drain, Heimlich valve, or other device to provide one-way flow of gas out of the chest
- Christmas tree adapter (to connect one-way valve to chest tube)
- Adhesive tape (2-inch waterproof)
- Elastic-Wrap bandage for a tourniquet (2 and 4 inch)
- Penrose Drain Tourniquet
- Bandage Scissors
- #11 knife blade and handle
- Curved Kelly forceps
- 10% povidone-iodine swabs or wipes
- 1% lidocaine solution
- #21 ga. 1-1/2" needles on 5 cc syringes
- Cravets
- 20 cc syringe

Table 8-6. Secondary Emergency Kit.

Emergency Airway Equipment

- Cuffed endotracheal tubes with adapters (7-9.5 mm)
- Syringe and sterile water for cuff inflation (10 cc)
- Malleable stylet (approx. 12" in length)
- Laryngoscope blades (McIntosh #3 and #4, Miller #2 and #3)
- Sterile lubricant
- soft rubber suction catheters
- #32F and #34F latex rubber nasal airways
- 5% or 2% lidocaine ointment

Drugs

- Lactated Ringer's Solution (3 ea 1-liter bags)
- Normal saline (2 ea 1-liter bags, 4 ea 250-ml bags for mixing drugs)
- * Atropine for injection (2 ea 1 mg)
- * Sodium bicarbonate for injection (8 ea mEg)
- * Verapamil for injection (4 ea 5 mg)
- * Dexamethasone for injection (4 ea 5 ml, 4 ea mg/ml)
- * Epinephrine (1/10,000) for injection (4 ea 1 mg)
- * Lidocaine for injection (4 ea 100 mg)
- * Diphenhydramine hydrochloride for injection (4 ea 50 mg)
- * Diazepam for injection (4 ea 10 mg)
- * Sodium phenytoin for injection (4 ea 250 mg)
- * Procainmide hydrochloride for injection (2 ea 1,000 mg)
- * Dopamine hydrochloride (4 ea 200 mg)
- * Furosemide for injection (4 ea 20 mg)
- * Bretylium tosylate (3 ea 500 mg)
- * Mannitol (4 ea 12.5 g in 50 ml)
- * Adenosine (4 ea 12 mg)
- * Sterile water for injection
- Asprin Tablets
- Asprin rectal suppositories

NOTE 1: Only commands having recompression chambers with a Medical Officer attached shall maintain a portable monitor-defibrillator and those drugs listed with an asterick (*).

NOTE 2: Whenever possible, preloaded syringe injection sets should be obtained to avoid the need to vent multidose vials or prevent implosion of ampules. Sufficient quantities should be maintained to treat one injured diver.

Table 8-6. Secondary Emergency Kit (continued).

Miscellaneous

- Nasogastric tube
- Urinary catheterization set with collection bag (Foley type)
- Catheter and needle unit, intravenous (16 and 18 gauge - 4 ea)
- Intravenous infusion sets (4)
- Intravenous infusion extension sets with injection ports (2)
- Straight and curved hemostats (2 ea)
- Blunt straight surgical scissors
- Thermometer (non-mercury type, high and low reading preferably)
- Syringes (2, 5, 10 and 30 cc)
- Sterile needles (18, 20 and 22 gauge)
- 3-way stopcocks
- Wound closure instrument tray
- Needle driver
- Assorted suture material (with and without needles)
- Assorted scapel blades and handle
- Surgical soap
- Sterile towels
- Sterile gloves (6-8)
- Gauze roller bandage, 1" and 2", sterile
- 10% povidone-iodine swabs or wipes
- Cotton Balls
- Gauze pads, sterile, 4" x 4"
- Band aids
- Splints
- Local ophthalmic anesthetic
- Eye patches
- Fluorescein strips

NOTE: A portable oxygen supply with an E cylinder (approximately 669 liters of oxygen) is recommended whenever possible, in the event the patient needs to be transported to another facility.

APPENDIX A

SYSTEM SAFETY CERTIFICATION OF U.S. NAVY DIVING SYSTEMS

A-1 PURPOSE AND SCOPE

All U.S. Navy diving systems are subject to the requirements of system safety certification. This appendix presents a brief introduction to the diving system safety certification process. The certification program is administered by the Naval Sea Systems Command (Code 00C4) for afloat and portable systems, Naval Sea Systems Command (Code 92Q) for submarine diving systems like the Dry Deck Shelter, and the Naval Facilities Engineering Command (Code 04B) for shore based facilities. Procedures and guidance are set forth in the *U.S. Navy Diving and Manned Hyperbaric Systems Safety Certification Manual*, SS521-AA-MAN-010. System safety certification is an independent systematic technical review to ensure that a diving system is capable of performing its intended function within acceptable limits of personnel safety, when used in accordance with approved operating and maintenance procedures. The primary objective of the certification process is to independently review the development of the system to ensure that it is properly designed, fabricated, installed, and tested. It is emphasized that the System Certification Authority (SCA), NAVSEA 00C4, NAVSEA 92Q, or NAVFAC 04B grants system safety certification based on a given set of design, operational, and maintenance parameters. These parameters, including operating procedures (OPs) and emergency procedures (EPs), shall not be changed without NAVSEA 00C3 or NAVFAC 04B approval as appropriate. The operational command is responsible to operate the system safely and to maintain it on a continuing basis during the tenure of certification.

System safety certification requirements apply to all diving systems, afloat and ashore, and to all U.S. Navy military and civilian diver-worn equipment that has not been listed in the Approved for Navy Use (ANU) List NAVSEA 10560.2 series. Certification of systems is required regardless of maximum operating depth. If a lease, charter, or contract for a diving system does not involve use of the equipment by U.S. Navy personnel, then the system need not be certified.

A handbook, *Continuation of Certification Handbook for U.S. Navy Diving Systems*, SS521-AB-HBK-010, was issued September 1991. This handbook is intended to be a useful tool to assist dive locker personnel in maintaining system certification of a Surface Supplied Diving System or a Recompression Chamber.

This handbook helps you prepare for the on-site survey. It identifies the type of items that the surveyor is looking for. The handbook also presents some completed sample PSOB's to aid in developing/updating your own.

A-2 CERTIFICATION APPROACH

The approach to certification of a diving system is as follows:

(1) Clearly identify the system sponsor, the SCA, and the chain of command linking the two.

(2) Identify diving operation requirements, including types of equipment to be used. Determine which components, procedures, and documents are subject to the certification process.

(3) Establish, in detail, the design configuration of the divers' breathing gas supply

system and determine that it meets quantity, flow, and pressure requirements. Ensure that the design was fabricated, installed, and tested in accordance with approved NAVSEA/NAVFAC plans, procedures, and guidance as applicable.

(4) Establish that supporting equipment and systems are adequate to support required diving or hyperbaric operations safely.

(5) Review system operating, emergency, and maintenance instructions to ensure compliance with pertinent directives and approved practices.

(6) Survey the installed system to verify the as-built configuration and material condition.

(7) Conduct a demonstration dive of the system to verify that it satisfactorily meets system objectives.

A-3 CERTIFICATION DOCUMENTATION

Technical documentation required in support of system certification is to be made available for SCA review. The documentation required for certification per SS521-AA-MAN-010 includes:

- Design Review Information
  - — System scope of certification
  - — Pre-survey outline booklet (PSOB)
  - — Summary description of diving or hyperbaric system
  - — Design parameters
  - — Subsystem descriptions
  - — Design analysis
  - — System drawings
  - — Operability and maintainability procedures
  - — Justification of materials
  - — Toxic and flammable materials data
  - — Atmosphere analysis
  - — Hyperbaric chamber vacuum data (if applicable)
  - — Hazard Analysis
- Fabrication Procedures
  - — Work procedures
  - — Process instructions
  - — Welding/Brazing procedures
  - — Assembly procedures
  - — Cleaning procedures
  - — Quality assurance procedures/data
  - — Design and drawing control data
  - — Material control data
  - — Fabrication and manufacturing control data
  - — Cleaning control
- Testing and Inspection Control
  - — Test plan
  - — Individual test procedures
  - — Test procedure index

— Test and inspection results

— Re-entry control data

- Operating Procedures

— Installation procedures

— Operating and emergency procedures (OPs and EPs)

— Operation and maintenance (O and M) manual (when required)

— Maintenance program

— Operating records

— Maintenance records

A-4 CUSTODY ACCOUNTING OF DIVING EQUIPMENT

Custody accounting encompasses NAVSEA property transfer and accounting requirements for all certified diving systems and equipment. Diving commands assigned custody of such equipment must maintain accurate records of the equipment's exact nomenclature, location, unit custodian, serial number, hull number, set number, or other permanently assigned designation. Such custody accounting is required to sustain system certification.

When permission to transfer the equipment has been requested and approved by appropriate authority, copies of formal transfer documents which provide positive identification of the equipment must be forwarded to NAVSEA Code 00C. When transfer of systems or equipment is permanent or for more than ninety calendar days, a new system certification process, as follows, is necessary.

(1) Revise all system documents to reflect new system sponsor.

(2) Request survey of equipment by SCA.

(3) Correct any category 1A or 1B system certification survey cards.

(4) If system was never certified, or certification has expired or been terminated prior to transfer, coordinate with SCA for scheduling of required demonstration dive.

System certification will be issued to a new sponsor only after all listed actions are completed. Should the equipment be returned to the original sponsor, the process will be repeated.

When transfer of class-certified diver worn equipment (e.g., MK 12 SSDS, MK 15 UBA, etc.) is authorized by SEA 00C, certification is unaffected and remains in effect.

A-5 ENGINEERING ALTERATIONS OF DIVER LIFE SUPPORT SYSTEMS AND EQUIPMENT

Policies and procedures for Diving Alterations (DIVEALTS) used to alter installed diving and hyperbaric equipment and systems within the Scope of Certification are presented in NAVSEAINST 10560.3, Diving Alterations (DIVEALTS) On Diver Life Support Systems (DLSS) and Equipment. DIVEALTS will be developed to correct DLSS deficiencies identified by Safety and Certification Surveys, IG Inspections, Pre-Overhaul Test and Inspections, other surveys and inspections, or by Ships Force during diving operations. The Supervisor of Diving, NAVSEA Code 00C3 administers the DIVEALT program. The Navy Experimental Diving Unit, Panama City, Florida, is the NAVSEA technical and management agent for the DIVEALT program. NAVSEA written approval is required prior to making any modification to a certified diving system.

APPENDIX B

ACCIDENT/INCIDENT EQUIPMENT INVESTIGATION REQUIREMENTS

B-1 INTRODUCTION

An **accident** is an unexpected event which culminates in loss of or serious damage to equipment or injury to personnel. An **incident** is an unexpected event which degrades safety and increases the probability of an accident.

The number of diving accidents/incidents involving U.S. Navy divers is small when compared to the total number of dives conducted each year. The mishaps which do occur, however, must receive a thorough review to identify the cause and determine corrective measures to prevent further diving mishaps.

Appendix B expands on OPNAVINST 3100.6 series and 5102.1 series which require expeditious reporting and investigation of all diving related mishaps which result in a fatality or in personnel injury where there is lost time of 60 hours or more. The accident/incident equipment status reporting procedures in this appendix apply, in general, to all diving mishaps when malfunction or inadequate equipment performance, or unsound equipment operating and maintenance procedures are a factor. Reporting criteria and required actions are specified in paragraphs B-2 and B-3. In many instances a Diving Life Support Equipment Failure Analysis Report (FAR) may also be required. The primary purpose of this requirement is to identify any material deficiency which may have contributed to the mishap. Any suspected malfunction or deficiency of life support equipment will be thoroughly investigated by controlled testing at the Navy Experimental Diving Unit (NEDU). NEDU has the capability to perform engineering investigations and full unmanned testing of all Navy diving equipment under all types of pressure and environmental conditions. Depth, water turbidity, and temperature can be duplicated for all conceivable U.S. Navy dive scenarios.

To assist diving units with investigations and data collection following a diving mishap, all equipment used must be assembled/packaged as a unit and sent by the fastest traceable means, to NEDU for full unmanned testing. Equipment must not be tampered with after the accident and must be sent "as was" to NEDU (see OPNAVINST 3150.27). The test results will provide specific data indicating whether the equipment performs in accordance with specifications, or if not, will identify the deficient areas.

Upon receipt of the defective equipment, NEDU will conduct unmanned tests as rapidly as possible and will then return the equipment to the appropriate activity. In the event immediate operational requirements dictate a need, NEDU will identify interim replacement equipment.

B-2 REPORTING CRITERIA

The diving and diving related accident/incident equipment status requirements set forth in this appendix are mandatory for all U.S. Navy diving units in each of the following circumstances:

(1) In all cases when an accident/incident results in a fatality or serious injury.

(2) Whenever an accident/incident occurs and a malfunction or inadequate performance of the equipment may have contributed to the accident/incident.

B-3 ACTIONS REQUIRED

U.S. Navy diving units shall perform the following procedure whenever a diving accident/incident/incident or related mishap meets the criteria stated in Paragraph B-2.

(1) Immediately secure and safeguard from tampering **all diver-worn and ancillary/support equipment** which **may** have contributed to the mishap. This equipment should also include, but is not limited to, the following: compressor, regulator, depth gauge, submersible pressure gauge, diver dress, buoyancy compensator/life preserver, weight belt, and gas supply (SCUBA, emergency gas supply (EGS), etc.).

(2) Expeditiously report circumstances of the accident/incident by message (see OPNAVINST 5102.1 series for format requirements) to NAVSAFECEN NORFOLK VA//JJJ// with info copies to COMNAVSEASYSCOM WASHINGTON DC//00C// and NAVXDIVINGU PANAMA CITY FL//JJJ//.

(3) Expeditiously prepare a **separate, written report** of the accident/incident. The report shall include:

(a) A completed Equipment Accident/Incident Information Sheet (Figure B-1)

(b) A completed Accident/Incident Equipment Status Data Sheet (Figure B-2)

(c) A sequential narrative of the mishap including relevant details that might not be apparent in the data sheets (Figures B-1 and B-2).

(d) The data sheets and the written narrative shall be mailed by traceable Registered Mail to:

Commanding Officer
Navy Experimental Diving Unit
321 Bullfinch Road
Panama City, Florida 32407-7015
Attn: Code 03, Test & Evaluation

NOTE

Call NEDU with details of the mishap or incident whenever possible. Personal contact may prevent loss of evidence vital to the evaluation of the equipment.

(4) Package and ship all equipment cited in paragraph B.3 (1) above with a certified copy of pertinent 3M records via the most expedient traceable means to the address in Paragraph B.3 (3d). NEDU must be notified by telephone or other electronic means, when the equipment is shipped and by what carrier.

NAVSEA 00C
Commercial: (703) 607-2766
Autovon: 327-2766

NEDU
Commercial: (904) 230-3100 or (904) 235-1668
Autovon: 436-4351

If the accident/incident is believed to be solely attributable to unsound operating and maintenance procedures, including publications, submit a NAVSEA (user) Technical Manual Deficiency/Evaluation Report (TMDER) and request guidance from NEDU to ascertain if shipment of all or part of the equipment is necessary.

In order to expedite delivery, SCUBA, MK 15/MK 16, and EGS bottles will be shipped separately in accordance with current DOT directives and command procedures for shipment of compressed gas cylinders. Cylinders will be forwarded in their exact condition of recovery (e.g., empty, partially filled, fully charged).

If the equipment which is believed to be contributory to the accident/incident is sufficiently large to preclude economical shipment, NEDU should be contacted to determine alternate procedures.

EQUIPMENT ACCIDENT/INCIDENT INFORMATION SHEET

GENERAL

Unit point of contact ______ Position ______

Command UIC ______ Date ______ Time of occurence ______

______

EQUIPMENT (indicate type of all equipment worn/used) Contributing factor? ______

UBA: SCUBA ______ MK 21 ______ MK 12 ______

MK 15 ______ MK 16 ______ LAR V ______

Other (specify) ______

Suit type: Dry ______ Wet ______ Hot water ______

Other dress: Gloves ______ Booties ______ Fins ______

Mask ______ Snorkel ______ Knife ______

Weight belt (indicate weight) ______

Depth gauge ______ Last calibration date ______

Buoyancy compensator/life preserver: ______

Inflated at scene: ______ Partially ______ Operational ______

Inflation mode: Oral ______ CO_2 ______ Independent supply ______

Cylinders: Number worn ______ Size (cu ft) ______ Valve type ______

Gas mix ______ Aluminum ______ Steel ______

Surface pressure: Before ______ After ______

Regulator: ______ Last PMS date? ______ Functional at scene? ______

Submersible Pressure Gauge: ______ Functional at scene? ______

CONDITIONS Location? ______

______

Depth ______ fsw Visibility ______ ft. Current ______ knots Sea state ______ (0-9)

Air temp ______ °F Water temp: at surface ______ °F at depth ______ °F

Bottom type (mud, sand, coral, etc.) ______

DIVE TIME

Bottom ______ Decompression ______ Total dive time ______

Was equipment operating and maintenance procedure a contributing factor?
(Explain): ______

Is there contributory error in O&M manual or 3M system?
(Explain): ______

OTHER CONTRIBUTING FACTORS ______

Figure B-1. Equipment Accident/Incident Information Sheet.

ACCIDENT/INCIDENT EQUIPMENT STATUS DATA SHEET

Pertaining to UBA involved, fill in blanks with data required by items 1 through 9.

MK 12 ⬇	MK 21 ⬇	MK 20 MOD 0 ⬇	Jack Browne ⬇	SCUBA ⬇	MK 15 ⬇	MK 16 ⬇	LAR V ⬇

1. Number of turns to secure topside gas umbilical supply:

				N/A	N/A	N/A	N/A

2. Number of turns to secure valve on emergency gas supply (EGS):

			N/A	Reserve Up/Down	N/A	N/A	N/A

3. Number of turns to secure gas supply at mask/helmet:

				N/A	Mouthpiece Valve: Surface ______ Dive ______	Mouthpiece Valve: Surface ______ Dive ______	Mouthpiece Valve: Surface ______ Dive ______

4. Number of turns to secure gas bottle:

N/A	N/A	N/A	N/A	Air Bottle ______	O_2 ______ Diluent ______	O_2 ______ Diluent ______	O_2 Bottle ______

5. Bottle Pressure:

EGS _____ psig	EGS _____ psig	EGS _____ psig	EGS _____ psig	_____ psig	O_2 _____ psig Diluent _____ psig	O_2 _____ psig Diluent _____ psig	_____ psig

6. Gas Mixture:

Primary % ______ EGS % ______	Primary % ______ EGS % ______			N/A	Diluent ______	Diluent N_2O_2 ______ HeO_2 ______	N/A

7. Data/color of electronic display:

N/A	N/A	N/A	N/A	N/A	Primary ______ Secondary ______ ______ ______	Primary ______ Secondary ______ ______ ______	N/A

8. Battery voltage level:

N/A	N/A	N/A	N/A	N/A	Primary ______ Secondary ______	Primary ______ Secondary ______	N/A

9. Condition of canistor:

	N/A	N/A	N/A	N/A			

Note: If UBA involved is not listed above, provide information on separate sheet.

Figure B-2. Accident/Incident Equipment Status Data Sheet.

APPENDIX C

FORMULAS AND CONVERSION FACTORS

C-1 FORMULAS

Tables C-1 through C-6 provide formulas and units related to air diving operations.

Actual cubic feet (acf) of a gas refers to the quantity measurement of a gas at ambient conditions.

Standard cubic feet (scf) is the most common unit of measurement for gas in the United States. It provides a means to relate the quantity measurement of a gas under pressure to a specific condition. This specific condition is a common basis for comparison. For air, the standard cubic foot is measured at 60° F and 14.696 psia.

Example: Find the actual cubic feet of air contained in a 700 cubic inch internal volume cylinder pressurized to 3,000 psi.

Solution:

Step 1. Obtain the number of standard cubic feet by using the following equation:

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

$$Where: T_1 = T_2$$

$$P_1 = 14.696\,psi$$

$$P_2 = 3{,}000\,psi + 14.696\,psi$$

$$V_1 = unknown$$

$$V_2 = 700\,in^3$$

$$P_1V_1 = P_2V_2$$

Step 2. Substitute known values and solve for V_1.

$$14.696\,psi \times V_1 = 3014.696\,psia \times 700\,in^3$$

$$V_1 = \frac{3014.696\,psia \times 700\,in^3}{14.696\,psi}$$

$$V_1 = 143{,}596.03\,in^3$$

Step 3. Convert V_1 to cubic feet:

$$V_1 = \frac{143{,}596.03\,in^3}{1728\,in^3/ft^3} = 83.1\,scf$$

C-2 CONVERSION TABLES

Figure C-1 and Tables C-7 through C-15 provide conversion data related to air diving operations.

Table C-1. Symbols and Values.

°F	Degrees Fahrenheit
°C	Degrees Celsius
A	Area
C	Circumference
D	Depth of Water
H	Height
L	Length
P	Pressure
r	Radius
T	Temperature
t	Time
V	Volume
W	Width
Dia	Diameter
Dia^2	Diameter Squared
Dia^3	Diameter Cubed
π	3.1416
$\pi/4$	0.7854
$\pi/6$	0.5236
ata	Atmospheres Absolute
pp	Partial Pressure
psi	Pounds per Square Inch
psig	Pounds per Square Inch Gauge
psia	Pounds per Square Inch Absolute
fsw	Feet of Sea Water
fpm	Feet per Minute
scf	Standard Cubic Feet
BS	Breaking Strain of Line or Rope
BTU	British Thermal Unit
cm^3	Cubic Centimeter
kw hr	Kilowatt Hour
SWL	Safe Working Load of Line or Rope

Table C-2. Lifting Capacity (In Pounds).

Fresh Water	$Lift = (V\ cu\ ft \times 62.4) - Weight\ of\ Lifting\ Unit$
Salt Water	$Lift = (V\ cu\ ft \times 64) - Weight\ of\ Lifting\ Unit$

Table C-3. Formulas for Area.

Square or Rectangle	$A = L \times W$
Circle	$A = 0.7854 \times Dia^2$ *or* $A = \pi r^2$

Table C-4. Formulas for Volumes.

Compartment	$V = L \times W \times H$
Sphere (balloon)	$= \pi \times 4/3 \times r^3$ $= \pi \times 4/3 \times (Dia/2)^3$ $= \pi \times 4/3 \times (1/2)^3 \times Dia^3$ $= \pi \times 4/3 \times 1/8 \times Dia^3$ $= \pi \times 1/6 \times Dia^3$ $= 0.5236 \times Dia^3$
Cylinder (pontoon)	$V = \pi \times r^2 \times L$ $= \pi \times (Dia/2)^2 \times L$ $= \pi \times (1/2)^2 \times Dia^2 \times L$ $= \pi \times 1/4 \times Dia^2 \times L$ $= 0.7854 \times Dia^2 \times L$

Table C-5. Formulas for Partial Pressure.

Partial Pressure Measured in psi	$pp = (D + 33\,fsw) \times \frac{0.445\ psi}{fsw} \times \left(\frac{\%V}{100\%}\right)$
Partial Pressure Measured in ata	$pp = \frac{D + 33\,fsw}{33\,fsw} \times \frac{\%V}{100\%}$
Partial Pressure Measured in fsw	$pp = (D + 33\,fsw) \times \frac{\%V}{100\%}$

Table C-6. Formulas for Seamanship (Note 1).

Breaking Strength (BS) in pounds for natural fiber	$BS = C^2 \times 900$		
Breaking Strength (BS) in pounds for synthetics	$BS = C^2 \times 2{,}400$ *Where C = line circumference in inches*		
Safe Working Load (SWL)	SWL = BS/safety factor below:		
	Rope Material	Standing Rigging	Running Rigging
	Manila	5	7
	Polypropylene	6	8
	Dacron	6	12
	Nylon	9	12
BS for Wire Rope	$BS = C^2 \times 8{,}000$		
SWL for Wire Rope	*SWL = BS/6* (Note 2)		
SWL for a Shackle	*SWL (in tons)* $= 6D^2$ *Where D = diameter of the bow*		
Hook Strength	A hook is approximately one-fifth as strong as a shackle. Measure hook diameter at the shank. A hook is the weakest part of a tackle.		

Notes:

1. The formulas listed above may be used to approximate Breaking Strength (BS) and Safe Working Load (SWL) when not available from other sources such as MILSPECs for BS or from SWL being stamped into shackles.

2. If the wire is new and in perfect condition, SWL can be increased by 30 percent. If the rope's condition is less than perfect, decrease the SWL by 30 percent. If sudden stress is a possibility, the SWL should be reduced by 50 percent. For standing rigging, the SWL can be doubled.

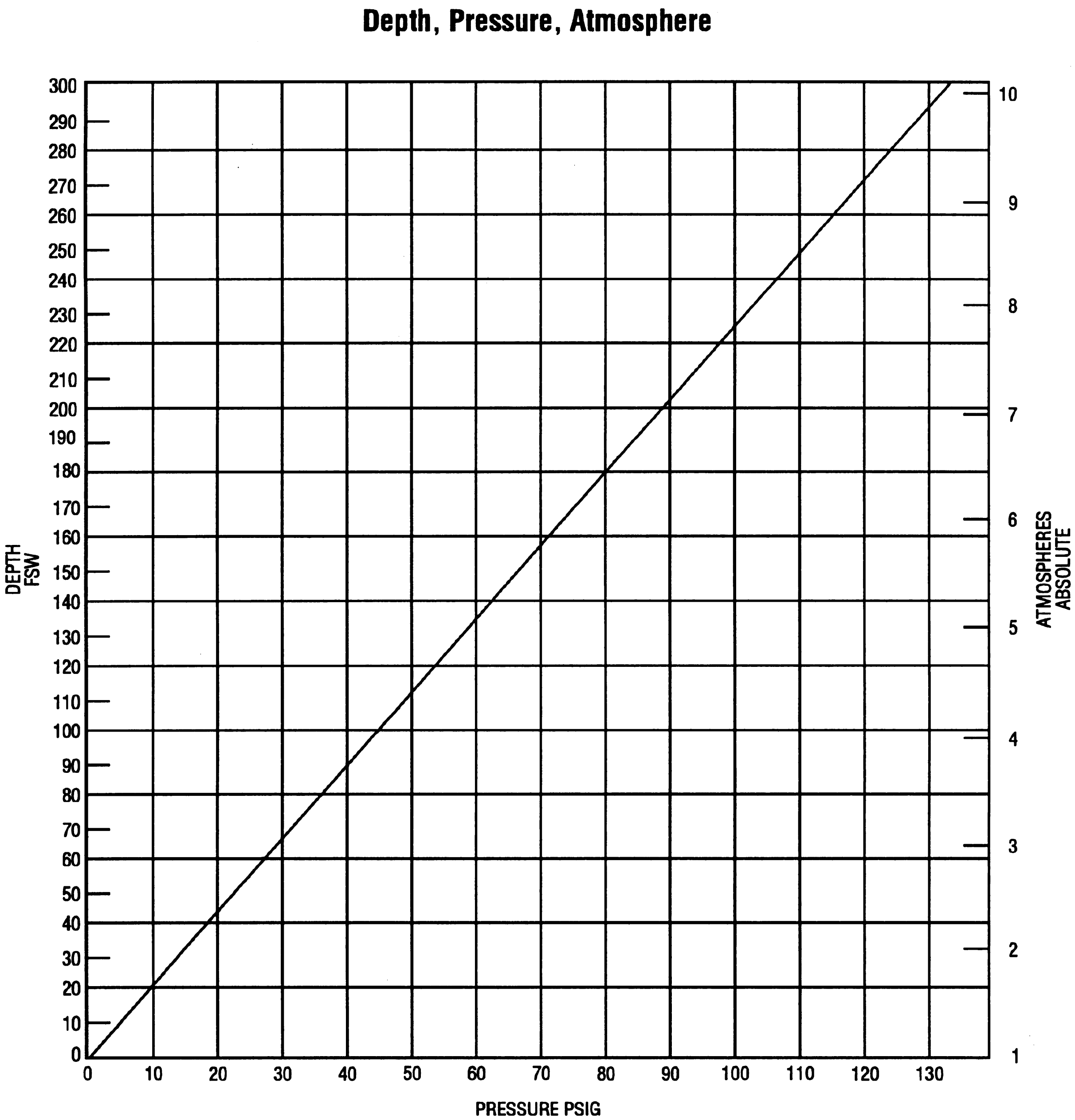


Figure C-1. Depth, Pressure, Atmosphere, Graph.

Table C-7. Pressure Equivalents.

Atmospheres	Bars	Kilograms Per Square Centimeter	Pounds Per Square Inch	Columns of Mercury at 0° C: Meters	Inches	Columns of Water * at 15° C: Meters (FW)	Inches (FW)	Feet (FW)	Feet (SW)
1	1.01325	1.03323	14.696	0.76	29.9212	10.337	406.966	33.9139	33.066
0.986923	1	1.01972	14.5038	0.750062	29.5299	10.2018	401.645	33.4704	32.6336
0.967841	0.980665	1	14.2234	0.735559	28.959	10.0045	393.879	32.8232	32.0026
0.068046	0.068947	0.070307	1	0.0517147	2.03601	0.703386	27.6923	2.30769	2.25
1.31579	1.33322	1.35951	19.3369	1	39.37	13.6013	535.482	44.6235	43.5079
0.0334211	0.0338639	0.0345316	0.491157	0.0254	1	0.345473	13.6013	1.13344	1.1051
0.09674	0.09798	0.099955	1.42169	0.073523	2.89458	1	39.37	3.28083	3.19881
0.002456	0.002489	0.002538	0.03609	0.001867	0.073523	0.02540	1	0.08333	0.08125
0.029487	0.029877	0.030466	0.43333	0.02241	0.882271	0.304801	12	1	0.975
0.030242	0.030643	0.031247	0.44444	0.022984	0.904884	0.312616	12.3077	1.02564	1

*** Note 1** **Fresh Water (FW) = 62.4 lbs/ft^3**
Salt Water (SW) = 64.0 lbs/ft^3

Table C-8. Volume and Capacity Equivalents.

Cubic Centimeters	Cubic Inches	Cubic Feet	Cubic Yards	Milliliters	Liters	Pint	Quart	Gallon
1	.061023	3.531×10^{-5}	1.3097×10^{-6}	.999972	9.9997×10^{-4}	2.113×10^{-3}	1.0567×10^{-3}	2.6417×10^{-4}
16.3872	1	5.787×10^{-4}	2.1434×10^{-5}	16.3867	0.0163867	0.034632	0.017316	4.329×10^{-3}
28317	1728	1	0.037037	28316.2	28.3162	59.8442	29.9221	7.48052
764559	46656	27	1	764538	764.538	1615.79	807.896	201.974
1.00003	0.0610251	3.5315×10^{-5}	1.308×10^{-6}	1	0.001	2.1134×10^{-3}	1.0567×10^{-3}	2.6418×10^{-4}
1000.03	61.0251	0.0353154	1.308×10^{-3}	1000	1	2.11342	1.05671	0.264178
473.179	28.875	0.0167101	6.1889×10^{-4}	473.166	0.473166	1	0.5	0.125
946.359	57.75	0.0334201	1.2378×10^{-3}	946.332	0.946332	2	1	0.25
3785.43	231	0.133681	4.9511×10^{-3}	3785.33	3.78533	8	4	1

Table C-9. Length Equivalents.

Centi-meters	Inches	Feet	Yards	Meters	Fathom	Kilo-meters	Miles	Int. Nau-tical Miles
1	0.3937	0.032808	0.010936	0.01	5.468×10^{-3}	0.00001	6.2137×10^{-5}	5.3959×10^{-6}
2.54001	1	0.08333	0.027778	0.025400	0.013889	2.540×10^{-5}	1.5783×10^{-5}	1.3706×10^{-5}
30.4801	12	1	0.33333	0.304801	0.166665	3.0480×10^{-4}	1.8939×10^{-4}	1.6447×10^{-4}
91.4403	36	3	1	0.914403	0.5	9.144×10^{-4}	5.6818×10^{-4}	4.9341×10^{-4}
100	39.37	3.28083	1.09361	1	0.5468	0.001	6.2137×10^{-4}	5.3959×10^{-4}
182.882	72	6	2	1.82882	1	1.8288×10^{-3}	1.1364×10^{-3}	9.8682×10^{-4}
100000	39370	3280.83	1093.61	1000	546.8	1	0.62137	0.539593
160935	63360	5280	1760	1609.35	880	1.60935	1	0.868393
185325	72962.4	6080.4	2026.73	1853.25	1013.36	1.85325	1.15155	1

Table C-10. Area Equivalents.

Square Miles	Square Centimeters	Square Inches	Square Feet	Square Yards	Acres	Square Miles
1	10000	1550	10.7639	1.19599	2.471×10^{-4}	3.861×10^{-7}
0.0001	1	0.155	1.0764×10^{-3}	1.196×10^{-4}	2.471×10^{-8}	3.861×10^{-11}
6.4516×10^{-4}	6.45163	1	6.944×10^{-3}	7.716×10^{-4}	1.594×10^{-7}	2.491×10^{-10}
0.092903	929.034	144	1	0.11111	2.2957×10^{-5}	3.578×10^{-8}
0.836131	8361.31	1296	9	1	2.0661×10^{-4}	3.2283×10^{-7}
4046.87	4.0469×10^{7}	6.2726×10^{6}	43560	4840	1	1.5625×10^{-3}
2.59×10^{6}	2.59×10^{10}	4.0145×10^{9}	2.7878×10^{7}	3.0976×10^{6}	640	1

Table C-11. Velocity Equivalents.

Centimeters Per Second	Meters Per Second	Meters Per Minute	Kilometers Per Hour	Feet Per Second	Feet Per Minute	Miles Per Hour	Knots
1	0.01	0.6	0.036	0.0328083	1.9685	0.0223693	0.0194673
100	1	60	3.6	3.28083	196.85	2.23693	1.94673
1.66667	0.016667	1	0.06	0.0546806	3.28083	0.0372822	0.0324455
27.778	0.27778	16.667	1	0.911343	54.6806	0.62137	0.540758
30.4801	0.304801	18.288	1.09728	1	60	0.681818	0.593365
0.5080	5.080×10^{-3}	0.304801	0.018288	0.016667	1	0.0113636	9.8894×10^{-3}
44.7041	0.447041	26.8225	1.60935	1.4667	88	1	0.870268
51.3682	0.513682	30.8209	1.84926	1.6853	101.118	1.14907	1

Table C-12. Mass Equivalents.

Kilograms	Grams	Grains	Ounces	Pounds	Tons (short)	Tons (long)	Tons (metric)
1	1000	15432.4	35.274	2.20462	1.1023×10^{-3}	9.842×10^{-4}	0.001
0.001	1	15.4324	0.035274	2.2046×10^{-3}	1.1023×10^{-6}	9.842×10^{-7}	0.000001
6.4799×10^{-5}	0.0647989	1	2.2857×10^{-3}	1.4286×10^{-4}	7.1429×10^{-8}	6.3776×10^{-8}	6.4799×10^{-8}
0.0283495	28.3495	437.5	1	0.0625	3.125×10^{-5}	2.790×10^{-5}	2.835×10^{-5}
0.453592	453.592	7000	16	1	0.0005	4.4643×10^{-4}	4.5359×10^{-4}
907.185	907185	1.4×10^{7}	32000	2000	1	0.892857	0.907185
1016.05	1.016×10^{6}	1.568×10^{7}	35840	2240	1.12	1	1.01605
1000	10^{6}	1.5432×10^{7}	35274	2204.62	1.10231	984206	1

Table C-13. Energy or Work Equivalents.

International Joules	Ergs	Foot - Pounds	International Kilowatt Hours	Horse Power Hours	Kilo - Calories	BTUs
1	10^{7}	0.737682	2.778×10^{-7}	3.7257×10^{-7}	2.3889×10^{-4}	9.4799×10^{-4}
10^{-7}	1	7.3768×10^{-8}	2.778×10^{-14}	3.726×10^{-14}	2.389×10^{-11}	9.4799×10^{-11}
1.3556	1.3556×10^{7}	1	3.766×10^{-7}	5.0505×10^{-7}	3.238×10^{-4}	1.285×10^{-3}
3.6×10^{6}	3.6×10^{13}	2.6557×10^{6}	1	1.34124	860	3412.76
2.684×10^{6}	2.684×10^{13}	1.98×10^{6}	0.745578	1	641.197	2544.48
4186.04	4.186×10^{10}	3087.97	1.163×10^{-3}	1.5596×10^{-3}	1	3.96832
1054.87	1.0549×10^{10}	778.155	2.930×10^{-4}	3.93×10^{-4}	0.251996	1

Table C-14. Power Equivalents.

Horse Power	International Kilowatts	International Joules/ Second	Kg.-M Second	Foot lbs. Per Second	IT Calories Per Second	BTUs Per Second
1	0.745578	745.578	76.0404	550	178.11	0.7068
1.34124	1	1000	101.989	737.683	238.889	0.947989
1.3412×10^{-3}	0.001	1	0.101988	0.737682	0.238889	9.4799×10^{-4}
0.0131509	9.805×10^{-3}	9.80503	1	7.233	2.34231	9.2951×10^{-3}
1.8182×10^{-3}	1.3556×10^{-3}	1.3556	0.138255	1	0.323837	1.2851×10^{-3}
5.6145×10^{-3}	4.1861×10^{-3}	4.18605	0.426929	3.08797	1	3.9683×10^{-3}
1.41483	1.05486	1054.86	107.584	778.155	251.995	1

Table C-15. Temperature Equivalents.

Conversion Formulas:

$$°C = (°F - 32) \times \frac{5}{9}$$

$$°F = (\frac{9}{5} \times °C) + 32$$

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
-100	-148.0	-60	-76.0	-20	-4.0	20	68.0	60	140.0	100	212.0	140	284.0
-98	-144.4	-58	-72.4	-18	-0.4	22	71.6	62	143.6	102	215.6	142	287.6
-96	-140.8	-56	-68.8	-16	3.2	24	75.2	64	147.2	104	219.2	144	291.2
-94	-137.2	-54	-65.2	-14	6.8	26	78.8	66	150.8	106	222.8	146	294.8
-92	-133.6	-52	-61.6	-12	10.4	28	82.4	68	154.4	108	226.4	148	298.4
-90	-130.0	-50	-58.0	-10	14.0	30	86.0	70	158.0	110	230.0	150	302.0
-88	-126.4	-48	-54.4	-8	17.6	32	89.6	72	161.6	112	233.6	152	305.6
-86	-122.8	-46	-50.8	-6	21.2	34	93.2	74	165.2	114	237.2	154	309.2
-84	-119.2	-44	-47.2	-4	24.8	36	96.8	76	168.8	116	240.8	156	312.8
-82	-115.6	-42	-43.6	-2	28.4	38	100.4	78	172.4	118	244.4	158	316.4
-80	-112.0	-40	-40.0	0	32	40	104.0	80	176.0	120	248.0	160	320.0
-78	-108.4	-38	-36.4	2	35.6	42	107.6	82	179.6	122	251.6	162	323.6
-76	-104.8	-36	-32.8	4	39.2	44	111.2	84	183.2	124	255.2	164	327.2
-74	-101.2	-34	-29.2	6	42.8	46	114.8	86	186.8	126	258.8	166	330.8
-72	-97.6	-32	-25.6	8	46.4	48	118.4	88	190.4	128	262.4	168	334.4
-70	-94.0	-30	-22.0	10	50.0	50	122.0	90	194.0	130	266.0	170	338.0
-68	-90.4	-28	-18.4	12	53.6	52	125.6	92	197.6	132	269.6	172	341.6
-66	-86.8	-26	-14.8	14	57.2	54	129.2	94	201.2	134	273.2	174	345.2
-64	-83.2	-24	-11.2	16	60.8	56	132.8	96	204.8	136	276.8	176	348.8
-62	-79.6	-22	-7.6	18	64.4	58	136.4	98	208.4	138	280.4	178	352.4

APPENDIX D

RECOMPRESSION CHAMBERS DESCRIPTION, OPERATION, AND MAINTENANCE

D-1 INTRODUCTION

Recompression chambers are used for the treatment of decompression sickness, for surface decompression, and for administering pressure tests to prospective divers. Recompression chambers equipped for hyperbaric administration of oxygen are also used in medical facilities for hyperbaric treatment of carbon monoxide poisoning, gangrenous tissue, and other diseases. Decompression surface supplied diving operations to depths greater than 130 fsw require that a chamber be available at the dive site.

D-2 DESCRIPTION

Most chamber-equipped U.S. Navy units will have one of three commonly provided chambers designed for permanent installation. They are:

(1) Double lock, 200-psig, 425-cubic-foot steel chamber (Figure D-1).

(2) Double lock, 100-psig, 201-cubic-foot aluminum chamber. Two-lock chambers of approximately 205-cubic-foot capacity or smaller may be used as fly-away or mobile chambers (Figure D-2).

(3) Double lock, 100-psig, 202-cubic-foot steel chamber (ARS 50) (Figures D-3 and D-4).

D-2.1 Basic Requirements. All U.S. Navy chambers are restricted to 100 psig maximum operating pressure. Double lock chambers are used because they permit tending personnel and supplies to enter and leave the chamber during treatment.

Navy chambers rated at the same pressure do not all have the same physical dimensions, with the exception of the aluminum chambers and ARS 50 chambers. Consequently, internal volumes of steel chambers are not standard and must be calculated for each chamber. The following equations can be used to approximate the internal volume of any U.S. Navy chamber.

V_c = *chamber volume in actual cubic feet (acf)*

$$= \frac{\pi D^2}{4} \times L$$

Where $\pi = 3.14$

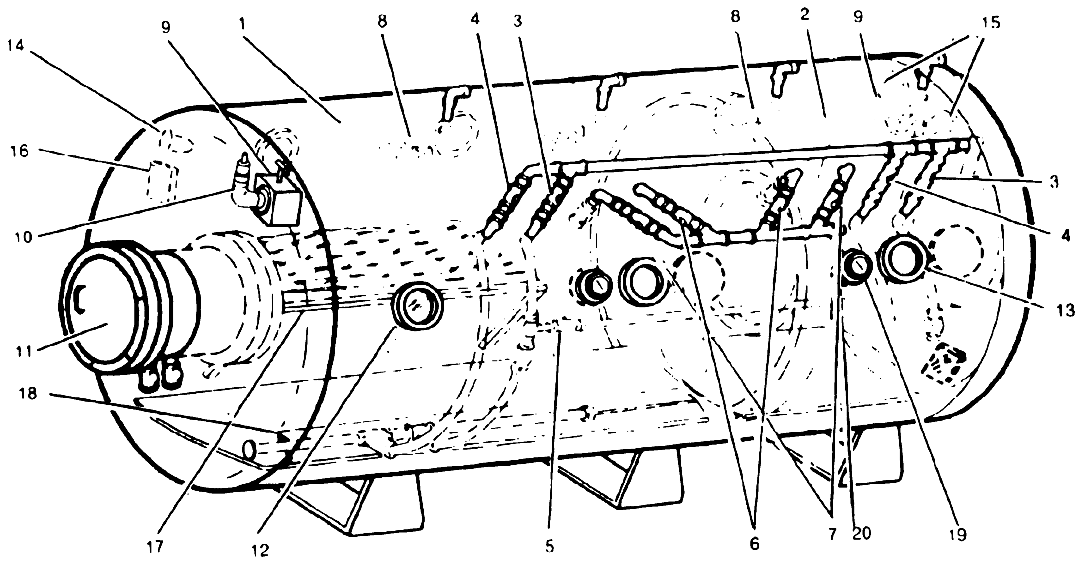
D = *inside diameter of shell in feet*

L = *overall inside length of chamber in feet*

The basic components of a recompression chamber are much the same from one model to another. They must be able to impose and maintain a pressure equivalent to a depth of 165 fsw (six atmospheres absolute). The piping and valving on some chambers is arranged to permit control of the air supply and the exhaust from either the inside or the outside of the chamber (Figure D-5). Controls on the outside must be able to override the inside controls in the event of a problem inside the chamber.

The usual method for providing this dual-control capability is through the use of two separate systems. The first, consisting of a supply line and an exhaust line, can only be controlled by valves which are outside of the chamber. The second air supply/exhaust system has a double set of valves, one inside and one outside the chamber. This arrangement permits the tender to regulate descent or ascent from within the

Double Lock Steel Recompression Chamber

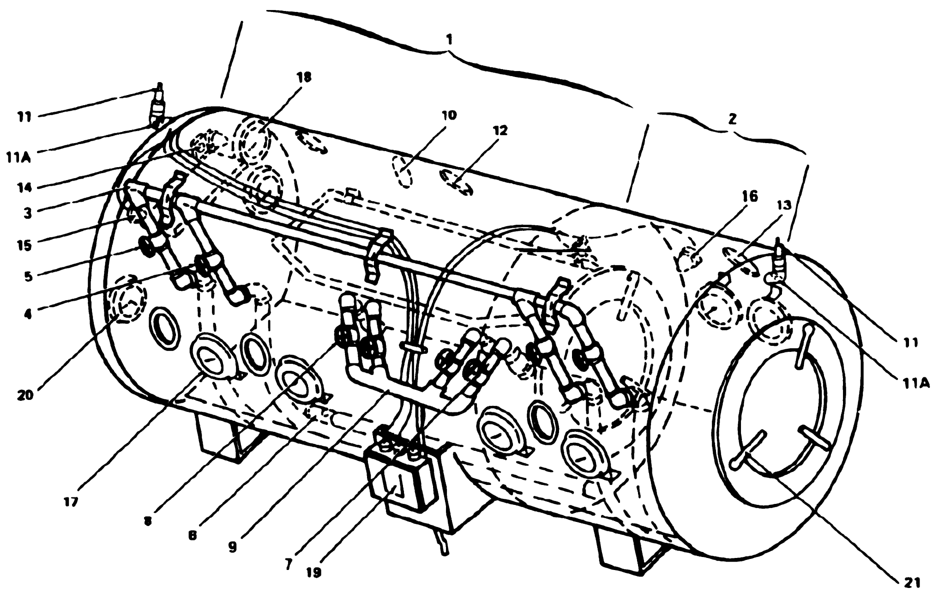


1. Inner Lock
2. Outer Lock
3. Air Supply – Two Valve
4. Air Supply – One Valve
5. Main Lock Pressure Equalizing Valve
6. Exhaust – Two Valve
7. Exhaust – One Valve
8. Oxygen Manifold
9. Relief Gag Valve (1 each Lock)
10. Relief Valve – 110 psig
11. Medical Lock 18-inch Diameter
12. Viewport – Inner Lock (4)
13. Viewport -- Outer Lock (2)
14. Lights – Inner Lock 40 Watt (4)
15. Lights – Outer Lock 40 Watt (4)
16. Transmitter/Receiver (2)
17. Berth – 2'6" x 6'6"
18. Bench
19. Pressure Gauge – Outside (2 each Lock)
20. Pressure Gauge – Inside (1 each Lock)

Original Design Pressure – 200 psig
Original Hydrostatic Test Pressure – 400 psig
Maximum Operating Pressure – 100 psig

Figure D-1. Double Lock Steel Recompression Chamber.

Double Lock Aluminum Recompression Chamber



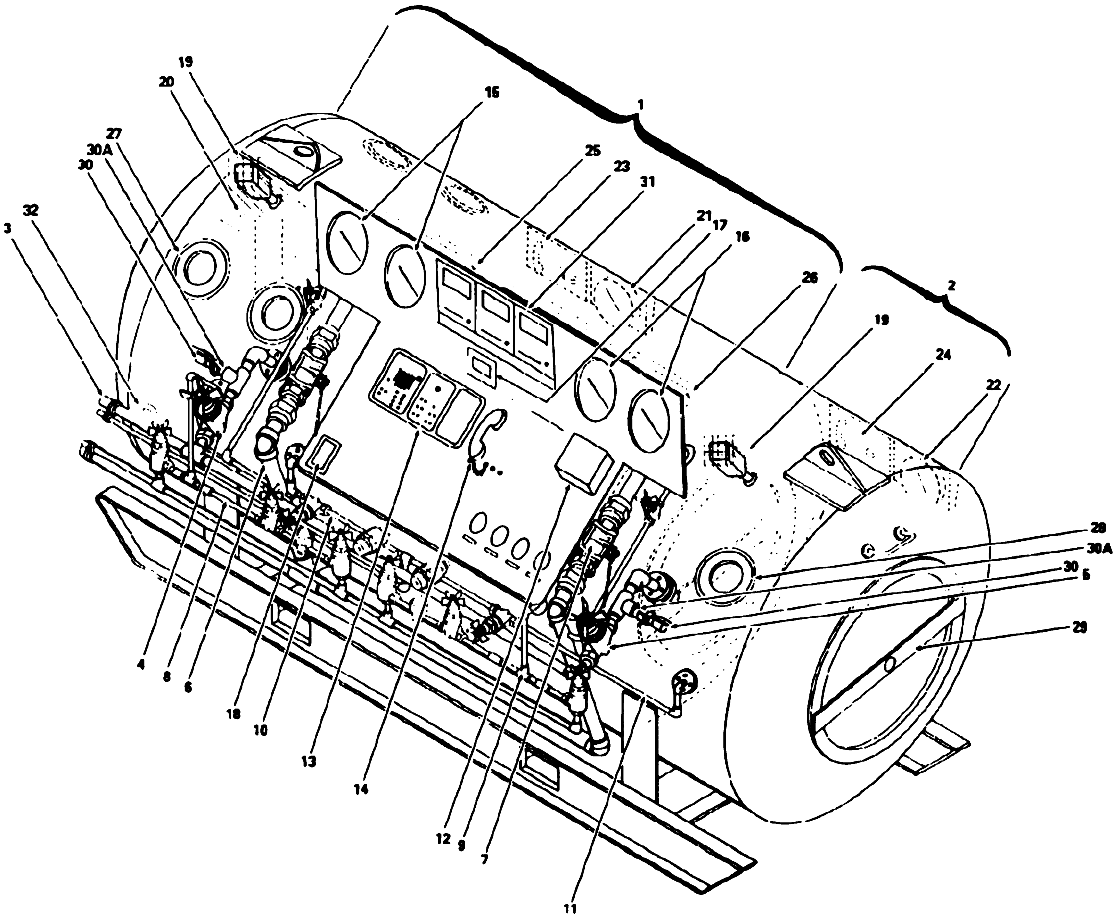
1. Inner Lock
2. Outer Lock
3. Air Supply Connection
4. Air Supply – Two Valve
5. Air Supply – One Valve
6. Inner Lock Pressure Equalizing Valve
7. Exhaust – Two Valve
8. Exhaust – One Valve
9. Exhaust Outlet
10. Oxygen Manifold
11. Relief Valve – 110 psig

11A. Gag Valve
12. Viewport – Inner Lock (4)
13. Viewport – Outer Lock (2)
14. Transmitter – Receiver (2)
15. Lights – Inner Lock 40 Watt (2)
16. Light – Outer Lock 40 Watt
17. Pressure Gauge – Outside (2 each Lock)
18. Pressure Gauge – Inside (1 each Lock)
19. Power Distribution Panel
20. Clock (optional)
21. Door Dogs

Design Pressure – 100 psig
Original Hydrostatic Pressure – 200 psig
Volume – Inner Lock = 136 cubic feet
– Outer Lock = 65 cubic feet
– Total = 201 cubic feet
Principal Locations – Repair/salvage ships and most shore-based facilities.

Figure D-2. Double Lock Aluminum Recompression Chamber.

ARS 50 Class Double Lock Recompression Chamber



1. Inner Lock
2. Outer Lock
3. Air Supply Connection
4. Air Supply – Inner Lock
5. Air Supply – Outer Lock
6. Exhaust – Inner Lock
7. Exhaust – Outer Lock
8. BIBS Supply – Inner Lock
9. BIBS Supply – Outer Lock
10. BIBS Exhaust – Inner Lock
11. BIBS Exhaust – Outer Lock
12. Oxygen Analyzer
13. Communications
14. Sound Powered Phones
15. External Depth Gauges – Inner Lock (2)
16. External Depth Gauges – Outer Lock (2)
17. Telethermometer
18. Ground Fault Interrupter
19. Pipe Light Assembly
20. Chiller and Scrubber Panel
21. Internal Depth Gauge – Inner Lock
22. Internal Depth Gauge – Outer Lock
23. Inner Lock Comm Panel
24. Outer Lock Comm Panel
25. Bunk Main
26. Bunk Extension
27. Viewports – Inner Lock (4)
28. Viewports – Outer Lock (2)
29. Strongback
30. Relief Valve – 110 psig

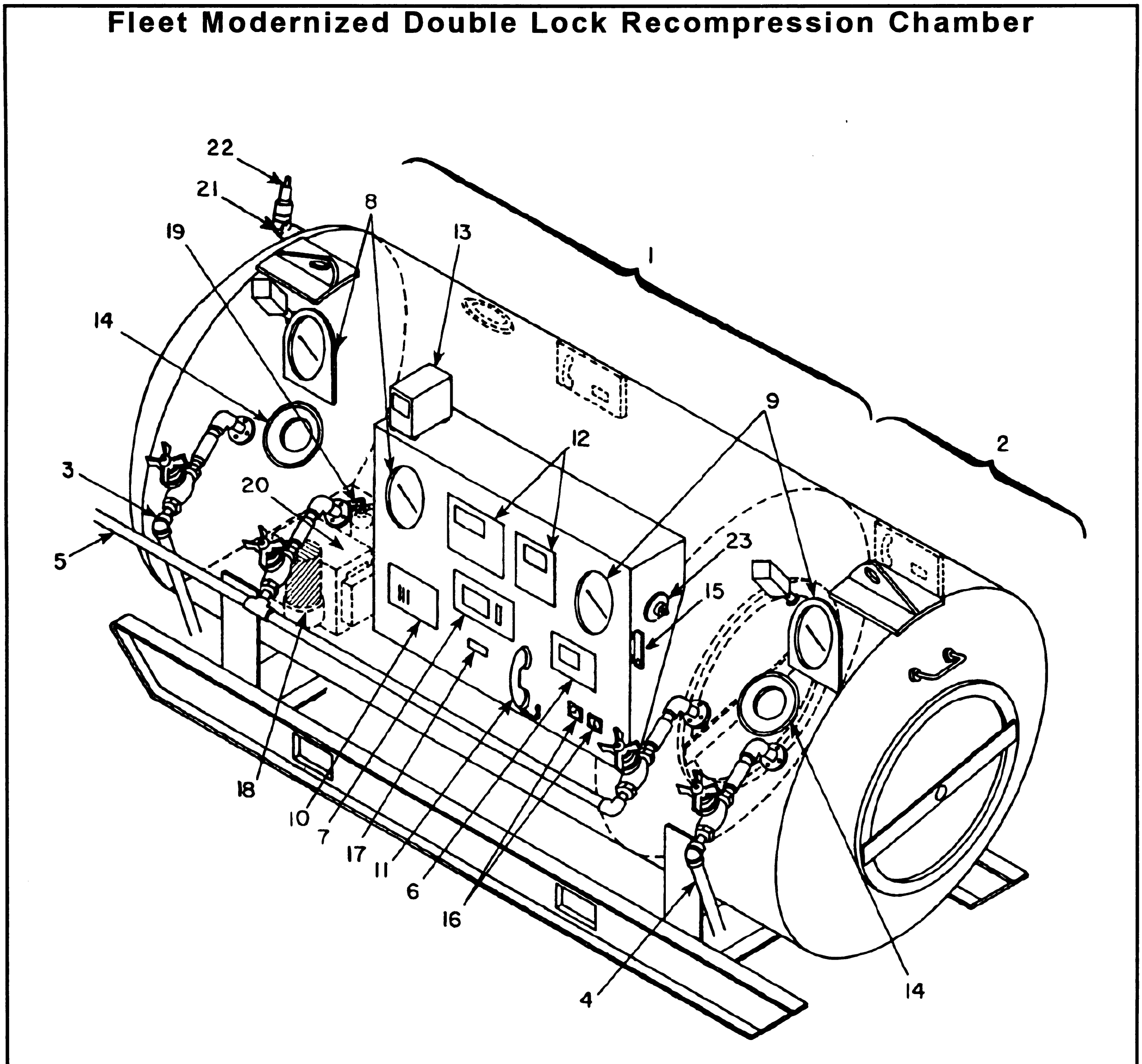
30A. Gag valve

31. Pipe Light Controls
32. Chiller/Scrubber Penetrator

Design Pressure – 100 psig
Original Hydrostatic Pressure – 150 psig
Principal Locations – ARS-50 Class Salvage Ships.

Volume - Inner Lock = 134 cubic feet
- Outer Lock = 68 cubic feet
- Total = 202 cubic feet

Figure D-3. ARS 50 Class Double Lock Recompression Chamber.



1. Inner Lock
2. Outer Lock
3. Gas Supply – Inner Lock
4. Gas Supply – Outer Lock
5. Gas Exhaust
6. O_2 Analyzer
7. CO_2 Analyzer
8. Inner Lock Depth Gauges (2)
9. Outer Lock Depth Gauges (2)
10. Communications Panel
11. Sound Power Phone
12. Pipe Light Control Panel
13. Ground Fault Interrupter
14. Viewports (5)
15. Flowmeter
16. Stopwatch/Timer
17. Telethermometer
18. CO_2 Scrubber
19. Fire Extinguisher
20. Chiller/Conditioner Unit
21. Gag Valve
22. Relief Valve - 110 psig
23. BIBS Overboard Dump Regulator - Outer Lock

Note: For BIBS system, see Figure D-6

Figure D-4. Fleet Modernized Double Lock Recompression Chamber.

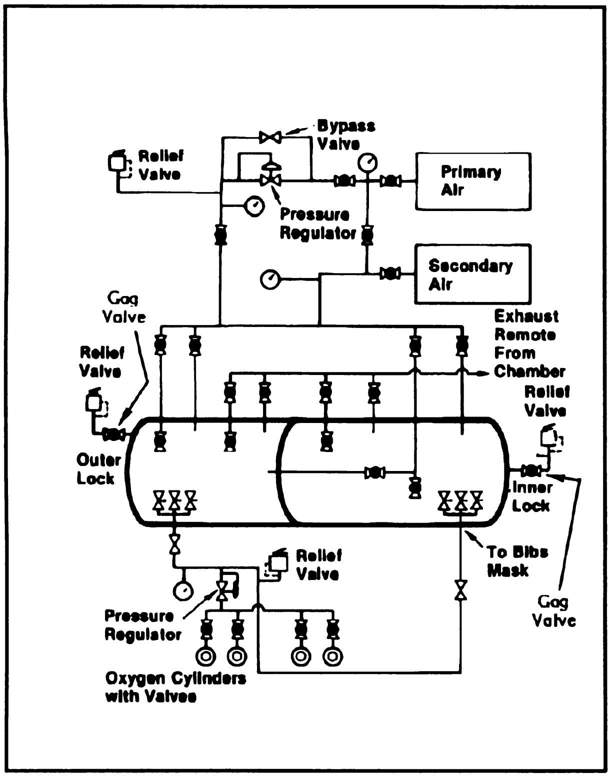


Figure D-5. General Recompression Chamber Gas Supply and Exhaust Drawing.

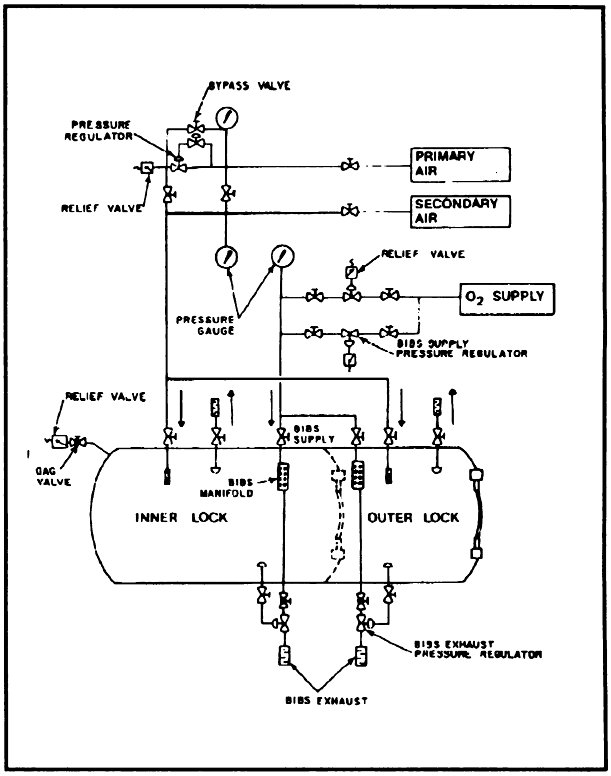


Figure D-6. Modernized Chamber Gas Supply and Exhaust Drawing.

chamber, but always subject to final control by outside personnel.

D-2.2 Modernized Chamber. Modernized chambers (Figures D-4 and D-6) have carbon dioxide and oxygen monitors, a CO_2 scubber system, a Built-In Breathing System (BIBS), and an oxygen dump system which together reduce the ventilation requirements.

The modernized chamber includes a chamber environment control system which regulates humidity and temperature. Modernized chambers have no internal lights, gauges, or valves; all controls, indicators, and lights for internal illumination are installed on the exterior of the chamber.

D-2.3 Transportable Recompression Chamber System. In addition to the chambers described above, a Transportable Recompression Chamber System (TRCS) is cuurently being introduced for fleet use (Figure D-7). The TRCS consists of two pressure chambers, one is a conical shaped chamber (Figure D-8) called the Transportable Recompression Chamber, and the other a cylindrical shaped vessel (Figure D-9) called the Transfer Lock (TL). The two chambers are capable of being connected by means of a freely rotating NATO female flange coupling.

When a recompression chamber is required, the TRCS will only be used in the double lock configuration to a maximum depth of 165 fsw. This configuration will support surface decompression using oxygen or air of one diver in accordance with the Surface Decompression Tables and Recompression Treatment Tables 1A, 2A, 5, 6 and 6A with all authorized extensions. The inner lock will only accomodate one patient and one attendant. The outer lock will only be used as a transfer lock for the exchange of attendants.

When a recompression chamber is not required,

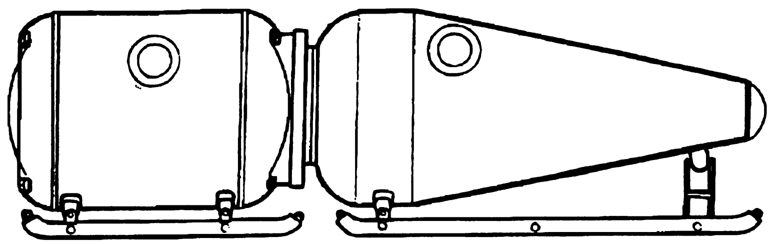
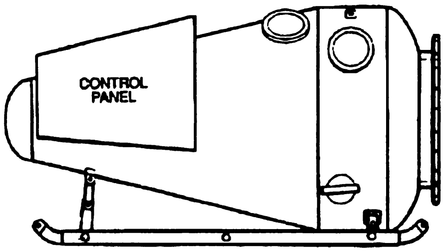


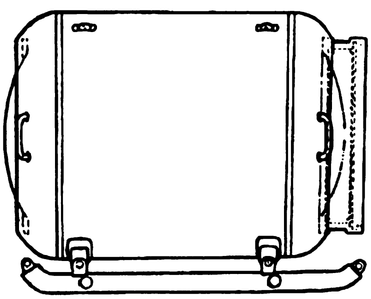
Figure D-7. Transportable Recompression Chamber System (TRCS).



Design Pressure	110 psig
Design Temperature	0° - 125°F
Dimensions	
Length	92"
Heigth	49"
Width	47"

Weigth	980 lbs.
Internal Volume	45 cu. ft.
Door Opening	24 1/2"
View Ports	3 @ 6" dia. Clear Opening
Medical Lock	5.75" dia. x 11.8" long
Mating Flange	Malr per NATO STANG 1079
Life Support	
Scrubber	Air driven, replacable scrubber canister fits in Med Lock
BIBS	2 masks - oxygen and air supply - overboard dump
Atmospheric Monitoring	Oxygen Analyzer
Gas Supply	Primary & secondary air & O_2
Communications	Battery powered speaker phone
Furnishing	Patient litter, attendants seat

Figure D-8. Transportable Recompression Chamber (TRC).



Design Pressure	110 psig
Design Temperature	0° - 125°F
Dimensions	
Length	60"
Heigth	48"
Width	45"
Weigth	1,090 lbs.

Internal Volume	44 cu. ft.
Door Opening	2 doors - 24 1/2" dia.
View Ports	2 @ 6" dia. clear opening
Mating Flange	Rotating Female per NATO STANG 1079
Life Suppport	
BIBS	2 masks - oxygen and air supply - overboard dump
Atmospheric Monitoring	Oxygen Analyzer
Gas Supply	Primary & secondary air & O_2
Communications	Sound powered phone

Figure D-9. Transfer Lock (TL).

the inner lock of the TRCS may be used to a maximum depth of 165 fsw in the single lock configuration for emergency recompression treatment in accordance with Recompression Treatment Tables 1A, 2A, 5, 6 and 6A with all authorized extensions. The inner lock will not be used for transport of patients to other recompression chambers while under pressure.

D-2.4 Standard Features. Recompression chambers must be equipped with a means for delivering breathing oxygen to the personnel in the chamber. The inner lock should be provided with connections for three or more demand-type oxygen inhalators. Oxygen can be furnished through a high-pressure manifold connected with supply cylinders outside the chamber (a minimum of two cylinders to permit change out). A medium-pressure high-capacity regulator must be located between the manifold and the through-hull penetrator of the chamber.

All lines should be identified and labeled to indicate function, content, and direction of flow. The color coding in Table D-1 should be used.

Table D-1. Recompression Chamber Line Guide.

Function	Designation	Color Code
Helium	HE	Buff
Oxygen	OX	Green
Helium-Oxygen Mix	HE-OX	Buff & Green
Nitrogen	N	Light Gray
Exhaust	E	Silver
Air (Low Pressure)	ALP	Black
Air (High Pressure)	AHP	Black
Chilled Water	CW	Blue & White
Hot Water	HW	Red & White
Potable Water	PW	Blue
Fire Fighting Material	FP	Red

Optimum chamber ventilation requires maximum separation of the inlet and exhaust ports within the chamber. Exhaust ports must be provided with a guard device to prevent accidental injury when they are open.

Chambers must be fitted with appropriate pressure gauges. These gauges, marked to read in feet of seawater (fsw), must be calibrated or compared as described in the applicable Planned Maintenance System (PMS) to ensure accuracy in accordance with the instructions in Appendix H.

All recompression chambers must be equipped with pressure relief valves in each manned lock. Chambers that do not have latches (dogs) on the doors are not required to have a relief valve on the outer lock. The relief valves must be set to relieve (lift) at 110 psig. In addition, all chambers shall be equipped with a gag valve, located between the chamber pressure hull and each relief valve. This gag valve shall be a quick-acting, ball-type valve, sized to be compatible with the relief valve and its supply piping. The gag valve shall be safety wired in the open position.

Chamber communications should be provided through an approved diver's intercommunication system, with the dual microphone/reproducer unit in the chamber and the surface unit outside. The communication system should be arranged so that personnel inside the chamber need not interrupt their activities to operate the system. The back-up communications system may be provided by a set of standard sound-powered telephones. The press-to-talk button on the set inside the chamber can be taped down, thus keeping the circuit open.

Consideration should be given to installation of a low-level lighting fixture (on a separate circuit), which can be used to relieve the patient of the heat and glare of the main lights. Emergency lights for both locks and an external control station are mandatory. No electrical equipment, other than that authorized for navy use as listed in NAVSEA Instruction 10560.2 series is allowed inside the chamber. Because of the possibility of fire or explosion when working in an oxygen or compressed air atmosphere, all electrical wiring and equipment used in a chamber must meet rigid specifications.

D-3 STATE OF READINESS

Since a recompression chamber is emergency equipment, it must be kept in a state of readiness. The chamber must be well maintained and equipped with all necessary accessory equipment. A chamber is not to be used as a storage compartment. The chamber, and the air and oxygen supply systems must be checked prior to each use with the Predive Checklist, and in accordance with PMS instructions. All diving personnel must be trained in the operation of the recompression chamber equipment and must be able to perform any task required during treatment.

D-4 GAS SUPPLY

A recompression chamber system must have a primary and a secondary air supply system which satisfy the following requirements.

- Primary - Sufficient air to pressurize the inner lock once to 165 feet and the outer lock twice to 165 feet and ventilate during one Treatment Table 4 (Chapter 8).

- Secondary - Sufficient air to pressurize the inner and outer locks once to 165 feet and ventilate for one hour at 70.4 scfm.

Either system may consist of air banks and/or a suitable compressor. The primary recompression chamber support system must be capable of pressurizing the inner lock to a depth of 165 feet within three minutes. The required total capacity is calculated as follows.

- Primary System Capacity:

$C_p = (5 \times V_{il}) + (10 \times V_{ol}) + 45{,}390$

Where: C_p *= minimum capacity of primary system in scf*

V_{il} *= volume of inner lock in scf*

V_{ol} *= volume of outer lock in scf*

5 = atmospheres equivalent to 165 fsw

10 = twice 5 atmospheres

45,390 = total air in scf required to ventilate during a Table 4 treatment

- Secondary System Capacity:

$C_s = (5 \times V_{il}) + (5 \times V_{ol}) + 4{,}224$

Where:C_s *= minimum capacity of secondary system in scf*

V_{il} *= volume of inner lock*

V_{ol} *= volume of outer lock*

5 = atmospheres equivalent to 165 fsw

4224 = air in scf required for maximum ventilation rate of 70.4 scfm for one hour (60 min)

D-5 OPERATION

D-5.1 Predive Checklist. To ensure each item is operational and ready for use, perform the equipment checks listed in the Recompression Chamber Predive Checklist, Figure D-10.

D-5.2 Safety Precautions.

- Do not use oil on any oxygen fitting, air fitting, or piece of equipment.

- Do not allow oxygen supply tanks to be depleted below 100 psig.

RECOMPRESSION CHAMBER PREDIVE CHECKLIST	
EQUIPMENT	**INITIALS**
CHAMBER	
System certified	
Clear of all extraneous equipment	
Clear of noxious odors	
Doors and seals undamaged, seals lubricated	
Pressure gauges calibrated/compared	
AIR SUPPLY SYSTEM	
Primary and secondary air supply adequate	
One-valve supply: Valve closed	
Two-valve supply: Outside valve open, inside valve closed, if applicable	
Equalization valve closed, if applicable	
Supply regulator set at 250 psig or other appropriate pressure	
Fittings tight, filters clean, compressors fueled	
EXHAUST SYSTEM	
One-valve exhaust: valve closed and calibrated for ventilation	
Two-valve exhaust: outside valve open, inside valve closed, if applicable	
OXYGEN SUPPLY SYSTEM	
Cylinders full, marked as BREATHING OXYGEN, cylinder valves open	
Replacement cylinders on hand	
Built in breathing system (BIBS) masks installed and tested	
Supply regulator set between 75 and 100 psig	
Fittings tight, gauges calibrated	
Oxygen manifold valves closed	
BIBS dump functioning	

Figure D-10. Recompression Chamber Predive Checklist (sheet 1 of 2).

RECOMPRESSION CHAMBER PREDIVE CHECKLIST		
EQUIPMENT		**INITIALS**
ELECTRICAL SYSTEM		
Lights		
Carbon dioxide analyzer calibrated		
Oxygen analyzer calibrated		
Temperature indicator calibrated		
Carbon dioxide scrubber operational		
Chamber conditioning unit operational		
Direct Current (DC) power supply		
Ground Fault Interrupter (GFI)		
COMMUNICATION SYSTEM		
Primary system tested		
Secondary system tested		
FIRE PREVENTION SYSTEM		
Tank pressurized for chambers with installed fire suppression systems		
Combustible material in metal enclosure		
Fire-resistant clothing worn by all chamber occupants		
Fire-resistant mattresses and blankets in chamber		
MISCELLANEOUS		
Inside Chamber:	CO_2 absorbent canister with fresh absorbent installed	
	Urinal	
	Primary medical kit	
	Ear protection sound attenuators/aural protectors (1 set per person)	
Outside Chamber:	Heater/chiller unit	
	Stopwatches for recompression treatment time, decompression time, personnel leaving chamber time, and cumulative time.	
	Fresh CO_2 scrubber canister	
	U.S. Navy Diving Manual, Volume 1	
	Ventilation bill	
	Chamber log	
	Operating Procedures (OPs) and Emergency Procedures (EPs)	
	Secondary medical kit	
	Bedpan (to be locked in as required)	

Figure D-10. Recompression Chamber Predive Checklist (sheet 2 of 2).

- Ensure dogs are in good operating condition and seals are tight.

- Do not leave doors dogged (if applicable) after pressurization.

- Do not allow open flames, smoking materials, or any flammables to be carried into the chamber.

- Do not permit electrical appliances to be used in the chamber unless authorized for navy use as listed in NAVSEA Instruction 10560.2 series.

- Do not perform unauthorized repairs or modifications on the chamber support systems.

- Do not permit products in the chamber which may contaminate or off-gas into the chamber atmosphere.

D-5.3 General Operating Procedures.

(1) Ensure completion of Predive Checklist.

(2) Diver and tender enter the chamber together.

(3) Diver will sit in an uncramped position.

(4) Tender close and dog (if so equipped) the inner lock door.

(5) Pressurize the chamber, at the rate and to the depth specified in the appropriate decompression or recompression table.

(6) As soon as a seal is obtained or upon reaching depth, tender will release the dogs (if so equipped).

(7) Ventilate chamber according to specified rates, and energize CO_2 scrubber and chamber conditioning system.

(8) Ensure proper decompression of all personnel.

(9) Ensure completion of Postdive Checklist.

During extensive treatments, medical personnel may prefer to lock-in, to examine the patient and then lock-out, rather than remain inside throughout the treatment. Inside tenders may tire and need relief.

In operation, the outer lock of a two-lock chamber is kept at atmospheric pressure while the patient and tender are inside the inner lock. Personnel entering the chamber go into the outer lock and close and dog the door (if applicable). The outer lock should be pressurized at a rate controlled by their ability to equalize, but not to exceed 75 feet per minute. The outside tender must record the time pressurization begins to determine the decompression schedule for the occupants when they are ready to leave the chamber. When the pressure levels in the outer and inner locks are equal, the inside door (which was undogged at the beginning of the treatment) should open.

To exit the chamber, the personnel again enter the outer lock and the inside tender closes and dogs the inner door (if so equipped). When ready to ascend, the Diving Supervisor is notified and the required decompression schedule is selected and executed. Constant communications are maintained with the inside tender to ensure that a seal has been made on the inner door. Outer lock depth is controlled throughout decompression by the outside tender.

The actuating lever of the chamber gag valves shall be maintained in the open position at all times, during both normal chamber operations and when the chamber is secured. The gag valves must be closed only in the event of relief valve failure during chamber operation. Valves are to be lock-wired in the open position with light wire that can be easily broken when required. A WARNING plate, bearing the inscription shown below, shall be affixed to the chamber in the vicinity of each gag valve and shall be readily viewable by operating personnel. The WARNING plates shall measure aproximately four inches by six inches and read as follows:

WARNING

This relief valve gag valve must remain in the open position at all times during normal chamber operation and when chamber is secured. Close only in event of relief valve failure and chamber depressurization is imminent.

D-5.4 Ventilation. The basic rules for ventilation are presented below. These rules permit rapid computation of the cubic feet of air per minute (acfm) required under different conditions as measured at chamber pressure (the rules are designed to ensure that the effective concentration of carbon dioxide will not exceed 1.5 percent (11.4 mmHg) and that when oxygen is being used, the percentage of oxygen in the chamber will not exceed 25 percent).

(1) When air is breathed, provide two cubic feet per minute (acfm) for each diver at rest and four cubic feet per minute (acfm) for each diver who is not at rest (i.e., a tender actively taking care of a patient).

(2) When oxygen is breathed from the built-in breathing system (BIBS), provide 12.5 acfm for a diver at rest and 25 acfm for a diver 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.

(3) If ventilation must be interrupted for any reason, the time should not exceed 5 minutes in any 30-minute period. When ventilation is resumed, twice the volume of ventilation should be used for the time of interruption and then the basic ventilation rate should be used again.

(4) If a BIBS dump system is used for oxygen breathing, the ventilation rate for air breathing may be used.

(5) If portable or installed oxygen and carbon dioxide monitoring systems are available, ventilation may be adjusted to maintain the oxygen level below 30 percent by volume and the carbon dioxide level below 1.5 percent surface equivalent (sev).

D-5.4.1 Chamber Ventilation Bill. 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. The standard procedure is to open the exhaust valve a given number of turns (or fraction of a turn), which will provide a certain number of cubic feet of ventilation per minute at a specific chamber depth, and to use the supply valve to maintain a constant chamber depth during the ventilation period. Determination of valve settings required for different amounts of ventilation at different depths is accomplished as follows.

WARNING

This procedure is to be performed with an unmanned chamber to avoid exposing occupants to unnecessary risks.

(1) Mark the valve handle position so that it

is possible to determine accurately the number of turns and fractions of turns.

(2) Check the basic ventilation rules above against probable situations to determine the rates of ventilation at various depths (chamber pressure) that may 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. It will be convenient to know the valve settings for rates such as 6, 12.5, 25, or 37.5 cubic feet per minute (acfm).

(3) Determine the necessary valve settings for the selected flows and depths by using a stopwatch and the chamber as a measuring vessel.

(a) Calculate how long it will take to change the chamber pressure by 10 feet if the exhaust valve lets air escape at the desired rate close to the depth in question. Use the following formula.

$$T = \frac{V \times 60 \times \Delta P}{R \times (D + 33)}$$

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 (cf)

R = rate of ventilation desired, in cubic feet per minute as measured at chamber pressure (acfm)

P = Change in chamber pressure in fsw

D = depth in fsw (gauge)

Example: Determine how long it will take the pressure to drop from 170 to 160 feet in a 425-cubic-foot chamber if the exhaust valve is releasing 6 cubic feet of air per minute (measured at chamber pressure of 165 feet).

Solution:

Step 1. List values from example.

T = unknown

V = 425 cf

R = 6 acfm

ΔP = 10 fsw

D = 165 fsw

Step 2. Substitute values in the previous equation.

$$T = \frac{425 \times 60 \times 10}{6(165 + 33)} = 215\ \textit{seconds}$$

$$T = \frac{215\ \textit{seconds}}{60\ \textit{seconds/minute}} = 3.6\ \textit{minutes}$$

(b) Increase the empty chamber pressure to 5 feet beyond the depth in question. Open the exhaust valve and determine how long it takes to come up 10 feet (for example, if checking for a depth of 165 fsw, take chamber pressure to 170 feet and clock the time needed to reach 160 feet). Open the valve to different settings until you can determine what setting will approximate the desired time. Record the setting. Calculate the times for other rates and depths and determine the settings for these times in the same way. Make a chart or table of valve setting versus ventilation rate and prepare a ventilation bill, using this information and the ventilation rules.

D-5.4.2 Notes On Chamber Ventilation.

- The basic ventilation rules are not intended to limit ventilation. Generally, if air is reasonably plentiful, more air than specified should be used for comfort. This increase is desirable because it also further lowers the concentrations of carbon dioxide and oxygen.

- 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 long periods of time.

- These rules assume that there is good circulation of air in the chamber during ventilation. If circulation is poor, the rules may be inadequate. Locating the inlet near one end of the chamber and the outlet near the other end improves ventilation.

- Coming up to the next stop reduces the standard cubic feet of gas in the chamber and proportionally reduces the quantity (scfm) of air required for ventilation.

- Continuous ventilation is the most efficient method of ventilation in terms of the amount of air required. However, it has the disadvantage of exposing the divers in the chamber to continuous noise. At the very high ventilation rates required for oxygen breathing, this noise can reach the level at which hearing loss becomes a hazard to the divers in the chamber. If high sound levels do occur, especially during exceptionally high ventilation rates, the chamber occupants must wear aural protectors (available as a stock item). A small hole should be drilled into the central cavity of the protector so that they do not produce a seal which can cause ear squeeze.

- The size of the chamber does not influence the rate (acfm) of air required for ventilation.

- 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 actual cubic feet (acfm) required.

- If high pressure air banks are being used for the chamber supply, pressure changes in the cylinders can be used to check the amount of ventilation being provided.

D-6 CHAMBER MAINTENANCE

D-6.1 Postdive Checklist. To ensure equipment receives proper postdive maintenance and is returned to operational readiness, perform the equipment checks listed in the Recompression Chamber Postdive Checklist, Figure D-11.

D-6.2 Scheduled Maintenance. Proper care of a recompression chamber requires both routine and periodic maintenance. Upon installation, at two-year intervals thereafter, after a major overhaul or repair, and each time it is moved, every USN recompression chamber must be pressure tested. This test shall be conducted in accordance with the pressure test for USN recompression chambers (Figure D-12) contained in this appendix. The completed test form shall be retained until retest is conducted. Chamber relief valves must be tested in accordance with the Planned Maintenance System to verify setting. Each tested relief valve must be tagged to indicate the valve set pressure, date of test, and testing activity. After every use or once a month, whichever comes first, the chamber must receive routine maintenance in accordance with the Postdive Checklist. At this time, minor repairs must be made and used supplies must be restocked.

RECOMPRESSION CHAMBER POSTDIVE CHECKLIST	
EQUIPMENT	**INITIALS**
AIR SUPPLY	
All valves closed	
Air banks recharged, gauged, and pressure recorded	
Compressors fueled and maintained per technical manual/PMS requirements	
Two-valve supply - outside valve opened	
VIEWPORTS AND DOORS	
Viewports checked for damage; replaced as necessary	
Door seals checked, replaced as necessary	
Door seals lightly lubricated with approved lubricant	
Door dogs and dogging mechanism checked for proper operation and shaft seals for tightness	
CHAMBER	
Inside wiped clean with Nonionic Detergent (NID) and warm fresh water	
All but necessary support items removed from chamber	
Blankets cleaned and replaced	
All flammmable material in chamber encased in fire-resistant containers	
Primary medical kit restocked as required	
Chamber aired out	
Outer door closed	
CO_2 canister packed	
Deckplates lifted, area below deckplates cleaned, deckplates reinstalled	
SUPPORT ITEMS	
Stopwatches checked and reset	
USN Diving Manual, Operating Procedures (OPs), Emergency Procedures (EPs), ventilation bill, and pencil available at control desk	
Secondary medical kit restocked as required and stowed	
Fire-retardent clothing cleaned and stowed	
All entries made in chamber log book	
Chamber log book stowed	

Figure D-11. Recompression Chamber Postdive Checklist (sheet 1 of 2).

RECOMPRESSION CHAMBER POSTDIVE CHECKLIST	
EQUIPMENT	**INITIALS**
OXYGEN SUPPLY	
BIBS mask removed, cleaned per current PMS procedures, reinstalled	
All valves closed	
System bled	
Breathing oxygen cylinders fully pressurized	
Spare cylinders available	
System free of contamination	
EXHAUST SYSTEM	
One-valve exhaust - valves closed	
Two-valve exhaust - inside valves closed	
Two-valve exhaust - outside valves opened	
ELECTRICAL	
All circuits checked	
Light bulbs replaced as necessary	
Pressure-proof housing of lights checked	
All power OFF	
Wiring checked for fraying	

Figure D-11. Recompression Chamber Postdive Checklist (sheet 2 of 2).

PRESSURE TEST FOR USN RECOMPRESSION CHAMBERS

NOTE

All U.S. Navy standard recompression chambers are restricted to a maximum pressure of 100 psig, regardless of design pressure rating.

A pressure test must be conducted on every USN recompression chamber:

- When initially installed
- When moved and re-installed
- At two-year intervals at a given location.

Performance of the test and the test results are recorded on a standard U.S. Navy Recompression Chamber Air Pressure and Leak Test form attached

The test is conducted as follows:

1. Pressurize the innermost lock to 100 fsw (45 psig). Using soapy water or an equivalent solution, leak test all shell penetration fittings, viewports, dog seals, door dogs (where applicable), valve conections, pipe joints and shell weldments.
2. Mark all leaks. Depressurize the lock and adjust, repair or replace components as necessary to eliminate leaks.
   a. Viewport leaks - Remove the viewport gasket (replace if necessary), wipe clean.

CAUTION

Acrylic viewports should not be lubricated or come in contact with any lubricant. Acrylic viewports should not come in contact with any volatile detergent or leak detector (non-ionic detergent is to be used for leak test). When reinstalling viewport, take up retaining ring bolts until the gasket just compresses evenly about the viewport. Do not overcompress the gasket.

   b. Weldment Leaks - Contact appropriate NAVSEA technical authority for guidance on corrective action.

3. Repeat steps 1 and 2 until all the leaks have been eliminated.
4. Pressurize lock to 225 fsw (100 psig) and hold for 5 minutes.
5. Depressurize the lock to 165 fsw (73.4 psig). Hold for 1 hour. If pressure drops below 145 fsw (65 psig), locate and mark leaks. Depressurize chamber and repair leaks in accordance with Step 2 above and repeat this procedure until final pressure is at least 145 fsw (65 psig).
6. Repeat Steps 1 through 5 leaving the inner door open and outer door closed. Leak test only those portions of the chamber not previously tested.

Figure D-12. Pressure Test for USN Recompression Chambers (sheet 1 of 3).

STANDARD U.S. NAVY RECOMPRESSION CHAMBER
AIR PRESSURE AND LEAK TEST
(Sheet 2 of 3)

Ship/Platform/Facility ______________________________

Type of Chamber: Double Lock Aluminum
Double Lock Steel
Portable Recompression Chamber
Other * ______________________

NAME PLATE DATA

Manufacturer ______________________________

Date of Manufacture ______________________________

Contract/Drawing No. ______________________________

Maximum Working Pressure ______________________________

Date of Last Pressure Test ______________________________

Test Conducted by ______________________________
(Name/Rank)

1. Conduct visual inspection of chamber to determine is ready for test.

   Chamber Satisfactory ______________ Initials of Test Conductor __________

   Discrepancies from fully inoperative chamber equipment:

   ____
   ____
   ____
   ____

2. Close inner lock door. With outer lock door open pressurize inner lock to 100 fsw (45 psig) and verify that the following components do not leak:
   (Note: If chamber has medical lock open inner door and close and secure outer door).

   Inner lock leak checks — Initials of Test Conductor

   A. Shell Penetrations and Fittings ______________ Satisfactory
   B. View Ports ______________ Satisfactory
   C. Door Seals ______________ Satisfactory
   D. Door Dog Shaft Seals ______________ Satisfactory
   E. Valve Connections and Stems ______________ Satisfactory
   F. Pipe Joints ______________ Satisfactory
   G. Shell Welds ______________ Satisfactory

3. Increase inner lock pressure to 225 fsw (100 psig) and hold for 5 minutes.
   Record Test Pressure ______________ Satisfactory ______________
   (Note: Disregard small leaks at this pressure).

Figure D-12. Pressure Test for USN Recompression Chambers (sheet 2 of 3).

STANDARD U.S. NAVY RECOMPRESSION CHAMBER
AIR PRESSURE AND LEAK TEST
(Sheet 3 of 3)

4. Depressurize lock slowly to 165 fsw (73.4 psig). Secure all supply and exhaust valves and hold for one hour.

   Start Time ________________ Pressure 165 fsw

   End Time ________________ Pressure ________ fsw

   Criteria: If pressure drops below 145 fsw (65 psig) locate and mark leaks. Depressurize, repair and retest inner lock.

   Inner Lock Pressure drop test passed Satisfactory ______________ Initials of Test Conductor

5. Depressurize inner lock and open inner lock door. Secure in open position. Close outer door and secure.

   (Note: If chamber has medical lock close and secure inner door and open outer door).

6. Repeat tests of sections 2, 3 and 4 above when setup in accordance with section 5. Leak test only those portions of the chamber not tested in sections 2, 3 and 4.

7. Outer Lock Checks

   Initials of Test Conductor

   A. Shell Penetrations and Fittings ______________________ Satisfactory

   B. View Ports ______________________ Satisfactory

   C. Door Seals ______________________ Satisfactory

   D. Door Dog Shaft Seals ______________________ Satisfactory

   E. Valve Connections and Stems ______________________ Satisfactory

   F. Pipe Joints ______________________ Satisfactory

   G. Shell Welds ______________________ Satisfactory

8. Maximum Chamber Operating Pressure (100 psig) Test (5 minute hold)

   Satisfactory ______________________ Initials of Test Conductor

9. Inner and Outer Lock Chamber Drop Test (Hold for one Hour).

   Start Time ______________________ Pressure 165 fsw

   End Time ______________________ Pressure ________ fsw

   Inner and outer lock pressure drop test passed satisfactorily ____________ Initials of Test Conductor

10. All above tests have been satisfactorily completed.

____

____
Test Director Signature — Date

____
Diving Officer — Date

____
Commanding Officer — Date

Figure D-12. Pressure Test for USN Recompression Chambers (sheet 3 of 3).

At the discretion of the activity, but at least once a year, the chamber should be inspected, both inside and outside. Any deposits of grease, dust, or other dirt should be removed and, on steel chambers, the affected areas repainted.

Corrosion is removed best by hand or by using a scrapper, being careful not to gouge or otherwise damage the base metal. The corroded area and a small area around it should then be cleaned to remove any remaining paint and/or corrosion.

Steel chambers shall then be painted as follows.

- **Inside:** One prime coat NSN 8010-01-302-3608

- One finish coat white NSN 8010-01-302-3606

- **Outside:** One prime coat NSN 8010-01-302-3608

- Two exterior coats gray NSN 8010-01-302-6838 or two exterior coats white NSN 8010-01-302-3606

Painting shall be kept to an absolute minimum. Only the coats prescribed above are to be applied. Naval Sea Systems Command will issue a Recompression Chamber Paint Process Instruction (NAVSEA-00C3-PI-001) on request.

If it is not known whether the steel chamber had previously been painted as above, remove all old paint and repaint. If paint exceeds five mils (0.005 inches), remove and repaint.

Only steel chambers are painted. Aluminum chambers are normally a dull, uneven graycolor and corrosion can be easily recognized. Aluminum chambers will not be painted.

The greatest single hazard in the use of a recompression chamber is from explosive fire. Fire may spread two to six times faster in a pressurized chamber than at atmospheric conditions because of the high partial pressure of oxygen in the chamber atmosphere. The following precautions must be taken to minimize fire hazard:

- Maintain the chamber oxygen percentage as close to 21% as possible and never allow oxygen percentage to exceed 25%.

- Remove any fittings or equipment which do not conform with the standard requirements for the electrical system or which are made of flammable materials. Permit no wooden deck gratings, benches, or shelving in the chamber.

- Equip the chamber with flameproof bedding material. Use only mattresses designed for hyperbaric chambers. Use (Durett Product) or submarine mattress (NSN 7210-00-275-5878 or 5874). Other mattresses may cause atmospheric contamination. Mattresses should be enclosed in flameproof covers or sheeting. Put no more bedding in a chamber than is necessary for the comfort of the patient. Never use blankets of wool or synthetic fibers because of the possibility of sparks from static electricity.

- Keep oil and volatile materials out of the chamber. If any have been used, ensure that the chamber is thoroughly ventilated before pressurization. Do not put oil on or in any fittings or high-pressure line. If oil is spilled in the chamber or soaked into any chamber surface or equipment, it must be completely removed. If lubricants are required, use only those approved and listed in Naval Ships Technical Manual (NSTM) NAVSEA S9086-H7-STM-000, Chapter 262. Regularly inspect and clean air filters and accumulators in the air supply lines to protect against the introduction of oil or other vapors into the chamber. Permit no one to wear oily clothing into the chamber.

- Permit no one to carry smoking materials, matches, lighters, or any flammable materials into a chamber. A WARNING sign should be posted outside the chamber. Example:

WARNING

Fire/Explosion Hazard. No matches, lighters, electrical appliances, or flammable materials permitted in chamber.

NAVSEAINST 10560.2 series, Diving Equipment Authorized For Navy Use, lists portable hyperbaric fire extinguishers authorized for use in recompression chambers. Fire extinguishers containing carbon tetrachloride, carbon dioxide, or dry powder must not be used. These chemicals are toxic in confined, pressurized atmospheres.

APPENDIX E

RECORD KEEPING AND REPORTING

E-1 INTRODUCTION

The record keeping and reporting instructions outlined in this appendix pertain to command diving logs, individual diving logs, personal diving records, diving mishap reports, and failure analysis reports.

There are four objectives in the diving record keeping and reporting system:

(1) Establish a comprehensive operational record for each diving command. The Command Smooth Diving Log is a standardized operational record prepared in accordance with established military practice. This record establishes the diving history for each diving command and constitutes the basic operational record requirement under normal, uneventful circumstances.

(2) Gather data for safety and trend analysis. Knowledge of current diving operations conducted in the Navy, and the incidence of equipment failures and diving mishaps is provided to the Naval Safety Center through the individual Diving Log Report system. This knowledge enables the Safety Center to identify safety-related problems associated with operating procedures, training, and equipment.

(3) Provide data for a personal record. OPNAVINST 3150.27 requires each diver to maintain a personal dive log/history.

(4) Report information about diving mishaps and casualties. Complete and accurate information enables the command to take appropriate action and prevent reoccurrence. In addition, information about equipment deficiencies is provided to the responsible technical agencies through the Failure Analysis Report system.

The documents established to meet the objectives outlined above are:

- Command Smooth Diving Log (Figure E-1)
- Diving Log (DD2544)
- Diver's Personal Log
- Diving Mishap/Hyperbaric Treatment/Death Report, Symbol OPNAV 5102/5
- Accident/Incident Equipment Status Report (See Appendix B of this manual.)
- Failure Analysis Report, NAVSEA Form 10560/4

E-2 COMMAND SMOOTH DIVING LOG

The Command Smooth Diving Log is a chronological record of all dives conducted at that facility or command, including dives conducted by visitors to the command, for example, personnel on travel. Dives conducted under the auspices of another command will be recorded as dives of the on-site (host) command in the Command Smooth Diving Log of that on-site command. It is required by OPNAVINST 3150.27 and will be maintained on file for three years. Data items to be included in the Command Smooth Diving Log are: identification of divers and standby divers, times left and reached surface, depth, bottom time, decompression

U.S. NAVY COMMAND SMOOTH DIVING LOG

Start Date ________________________________

End Date ________________________________

This Log must be maintained in accordance with the *U.S. Navy Diving Manual, Volume One,* (NAVSEA 0994-LP-001-9010).

Figure E-1. U.S. Navy Diving Log (sheet 1 of 2).

COMMAND SMOOTH DIVING LOG

Date	Geographic Location	Air Temp (°F)
Equipment Used	Dress	Wave Height (ft)
Breathing Medium	Platform	Water Temp (°F)
Breathing Medium Source		Current (kts)
Depth of Dive (fsw)	Bottom Type	Bottom Vis (ft)

Diver	LS	RB	LB	RS	TBT	TDT	TTD	Sched Used

Purpose of Dive, Tools Used, etc.	Repet Group
	Surface Interval
	New Repet Group
	RNT

Dive Comments

Signature (Diving Supervisor)

Signature (Master Diver)

Signature (Diving Officer)

Figure E-1. U.S. Navy Diving Log (sheet 2 of 2).

time, air and water temperature, purpose, and result of dive. The log can be supplemented as appropriate by other documents such as orders, dive plans, and other reports.

E-3 INDIVIDUAL DIVING LOG REPORT

The Diving Log, DD Form 2544 (NSN 0102-LF-008-5800), must be completed in accordance with OPNAVINST 3150.28 for every dive conducted under the auspices of the U.S. Navy. Dives will be recorded under the host command's Unit Identification Code (UIC).

The DD Form 2544, which has been revised, is a coded report form which records the data by means of entering letter and number codes on the form.

The DD Form 2544 should be sent within 10 days of the dive to:

COMMANDER
NAVAL SAFETY CENTER
CODE 532
NAVAL AIR STATION
NORFOLK, VA 23511-5796

E-4 DIVER'S PERSONAL DIVE LOG

While specific Navy Divers Personal Logbooks are no longer available, the requirement for each Navy trained diver to maintain a record of his dives still exists. The best way for each diver to accomplish this is to keep a copy of each Dive Log Form (DD Form 2544, formerly 3150 or 9940 form) in a binder or folder. These forms, when signed by the Diving Supervisor and Diving Officer are an acceptable record of dives which may be required to justify special payments made to you as a diver, and may help substantiate claims made for diving related illness or injury.

E-5 DIVING MISHAP/CASUALTY REPORTING

General instructions for special incident reporting are contained in OPNAVINST 3100.6C and ship, squadron and type commander instructions. Specific instructions for diving mishap, casualty, and hyperbaric treatment are provided in Chapter 8 of OPNAVINST 5102.1C. The Judge Advocate General Manual provides instructions for investigation and reporting procedures required in instances when the mishap may have occurred as a result of procedural or personnel error. Diving equipment status reporting instructions related to diving accidents/incidents are specified in Appendix B of this manual.

E-6 EQUIPMENT FAILURE OR DEFICIENCY REPORTING

The Failure Analysis Report (FAR) system provides the means for reporting, tracking, and resolving material failures or deficiencies in diving life-support equipment (LSE). The FAR was developed to provide a rapid response to diving LSE failures or deficiencies. It is sent directly to the configuration manager, engineers, and technicians who are qualified to resolve the deficiency. FAR Form 10560/4 (stock number 0116-LF-105-6020) covers all diving LSE not already addressed by other FARs or reporting systems. For example, the MK 1 MOD 0 Bandmask, MK 12 SSDS, and all open-circuit SCUBA are reportable on this FAR form; the UBAs MK 14, MK 15, MK 16, and LAR V are reportable on other FARs or reporting systems. When an equipment failure or deficiency is discovered, the Diving Supervisor or other responsible person will ensure that the FAR is properly prepared and distributed. Appendix B of this manual specifies additional reporting requirements for an equipment failure suspected as the cause of a diving accident.

The one page FAR form (Figure E-2) consists of an original and three copies. The completed original is maintained in the Command FAR Log; the copies are mailed to CSS (Code 2510), NAVSEA (Code OOC3) and NEDU (Code 03). Instructions for completion and distribution of the FAR are on the reverse side of the form.

E-7. U.S. NAVY DIVE REPORTING SYSTEM (DRS)

The DRS is a computer software package based on the dive recording and reporting requirements of OPNAVINST 3150.28. The software is intended to provide all Navy diving commands with a computer record of all dives they conduct and to make it easier to complete the Diving Log Form, DD 2544. The software allows users to enter dive data and to electronically generated the completed form. Completion of this form does not replace the requirement for commands and individual divers to maintain their own diving logs, however, copies can be easily produced for the individual diver for his personal use.

The DRS was designed for all branches of the U.S. Armed Services and can be obtained through:

COMMANDING OFFICER
NAVY EXPERIMENTAL DIVING UNIT
321 BULLFINCH ROAD
PANAMA CITY, FLORIDA 32406-5016
ATTN: CODE 01A

NAVAL SEA SYSTEMS COMMAND

DIVING LIFE SUPPORT EQUIPMENT FAILURE ANALYSIS REPORT (FAR)

(Read Instructions on Reverse)

1. REPORTING ACTIVITY NAME	2. UNIT IDENTIFICATION CODE ______ FAR SERIAL NO. ______	3. DATE PROBLEM DETECTED (MO/DAY/YR) ______

4. POINT OF CONTACT NAME: ______ TELEPHONE: ______	5. CLASSIFICATION (NCSC Use Only) 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
6. EQUIPMENT NAME	EQUIPMENT SERIAL NUMBER
7. ITEM NAME	PART NUMBER OR FEDERAL STOCK NUMBER

8. FAILURE

A. HOW DISCOVERED: ☐ PREDIVE ☐ OPERATING ☐ POSTDIVE ☐ PMS ☐ OTHER (Block 11)

B. TYPE: ☐ MALFUNCTION ☐ BROKEN OR DAMAGED ☐ TECH DOCUMENTATION ☐ OTHER (Block 11)

C. CAUSE: ☐ NORMAL WEAR ☐ HUMAN ERROR ☐ DESIGN FLAW ☐ PMS ☐ WRONG PARTS ☐ OTHER (Block 11)

9. SPARE PARTS PART CONTRACT NUMBER (XXXXXX - YY - X - XXXX)

☐ NOT AVAILABLE FROM STOCK ☐ IMPROPERLY PACKAGED ☐ DEFECTIVE ON RECEIPT

☐ DEFECTIVE ON TRIAL ☐ QUALITY DEFICIENCY REPORT (QDR) SUBMITTED ☐ OTHER (Block 11)

10. CORRECTION ☐ REPAIRED PARTS ☐ REPLACED PARTS ☐ OTHER (Block 11)

DATE COMPLETED: MAN HOURS: EST. COST OF PARTS:

11. COMMENTS (Reference Block Numbers)

NAVSEA 10560/4 (10/86)(Front) S/N 0116-LF-105-6020

Figure E-2. Failure Analysis Report (FAR) Form.

APPENDIX F

DIVING SYSTEM GAUGES

F-1 SELECTION OF GAUGES

Select a gauge whose full scale reading approximates four-thirds to five-thirds of the maximum operating pressure of the system. Therefore, a gauge with a full scale reading of 4000 or 5000 psi would be satisfactory for installation in a system with a maximum operating pressure of 3000 psi.

Selection of gauge accuracy and precision should be based on the type of system and the use of the gauge. A high level of precision is not required, for example, on air bank pressure gauges, where only relative values are necessary to determine how much air is left in the bank or when to shut down the charging compressor. However, considerable accuracy (1/4 of 1 percent of full scale for saturation diving operations and 1 percent of full scale for surface-supplied operations) is required for gauges that read diver depth (pneumofathometers and chamber depth gauges). Depth gauge accuracy is critical to the selection of the proper decompression or treatment table.

Many gauges are provided with a case blowout plug on the rear surface. This blowout plug serves to protect the operator in the event of Bourdon tube failure, when case overpressurization could otherwise result in explosion of the gauge lens. The plug must not be obstructed by brackets or other hardware.

All diving system gauges should be provided with gauge isolation valves and calibration fittings. In the event of a gauge failure during an operation, the isolation valve is closed to prevent loss of system pressure.

F-2 CALIBRATION AND MAINTENANCE OF GAUGES

All installed gauges and portable gauges (tank pressure gauges, submersible tank pressure gauges, and gauges in small portable test sets) in use must be calibrated or compared in accordance with the Planned Maintenance System schedule unless a malfunction requires repair and calibration sooner. Installed gauges must be calibrated annually; portable gauges must be calibrated semiannually. Programs such as the Shipboard Gauge Calibration Program as outlined in NAVSEA Instruction 4734.1 provide authority for a command to calibrate it's own gauges. Calibrated gauges not in use should be kept in a clean, dry, vibration-free environment. The Meterology Requirements List, NAVSEA OD-45845, should be consulted to determine storage times not considered part of the calibration interval.

Calibration and comparison data must include the date of the last satisfactory check, the date the next calibration is due, and the activity accomplishing the calibration. Labels attached to gauge lens are satisfactory for recording this data.

When oxygen systems are being cleaned, gauge lines should be removed and cleaned separately, after first cleaning the system with gauge lines attached. This will ensure that the gauge lines are thoroughly flushed. All gauges should be removed from the system prior to the cleaning process to avoid dead ends in the system and damage to the gauges from the cleaning solution.

Gauges are delicate instruments and can be damaged by vibration, shock, or impact. They should be mounted in locations which minimize these factors and should always be mounted to gauge boards, panels, or brackets. The piping connection should not be the sole support for the gauge. A gauge can be severely damaged by rapid pulsations of the system when the fluid pressure is being measured. When this condition exists, a gauge snubber should be installed between the isolation valve and the gauge to protect the instrument. Most gauges are not waterproof and are not designed for use in a marine environment. Care must be used in protecting the gauges from water and salt spray.

Transparent acrylic plastic (lucite, etc.) enclosures are useful. However, vent passages must be provided to permit the atmospheric pressure to act on the gauge sensing element.

F-3 HELICAL BOURDON TUBE GAUGES

Manufacturers make two basic types of helical Bourdon tube gauges for use on recompression chambers and for surface-supplied diving systems. One is a caisson gauge with two ports on the back. The reference port, which is capped, is sealed with ambient air pressure or is piped to the exterior of the pressure chamber. The sensing port is left open to interior pressure. The other gauge is the standard exterior gauge. Both are direct drive instruments employing a helical Bourdon tube as the sensing element. The gauges are accurate to 1/4 of 1 percent of full scale pressure at all dial points. With no gears or linkages, the movement is unaffected by wear, and accuracy and initial calibration remains permanent. A comparative check in lieu of recalibration should be made in accordance with the Planned Maintenance System. A dial adjustment screw on the front face of the gauge provides for zero point adjustment and special set pressure. Dial readout units of measure can be in pounds per square inch (psi) and/or feet of seawater (fsw).

APPENDIX G

DANGEROUS MARINE ANIMALS

It is beyond the scope of this manual to catalog all the treatments of marine encounters or injury. There are, however, general principles that will prove useful. One should consult the recommended references for more definite and up to date information. Diving Medical Officers should be consulted prior to assignment to specifically hazardous areas such as the Indo-Pacific. Nevertheless, a knowledge of the marine environment may preclude lost time from duty and/or severe injury.

G-1 PREDATORY MARINE ANIMALS

G-1.1 Sharks. Shark attacks on humans are infrequent. Since 1965, the annual recorded number of shark attacks is only 40 to 100 worldwide. These attacks are unpredictable and injuries may result not only from bites, but also by coming in contact with the shark's skin which is covered with very sharp dentine appendages, called denticles, and which are reinforced with a tooth-like center. Contact with shark skin can lead to wide abrasions and heavy bleeding.

The reasons for shark attacks on humans are not known entirely. In some cases, humans may be mistaken as natural prey (i.e., seals, fish). A black wet suit may even enhance this impression. Sharks may be attracted by the smell of blood - for example, from spearfishing - which they can detect in concentrations as low as one part per million (ppm). Low frequency vibrations, such as underwater explosions, the thrashing of a fish, or someone splashing on the surface, which sharks are very sensitive to, may also attract these predators. Sharks may also be triggered to attack by brightly colored or shiny metallic objects, such as jewelry.

Pre-attack behavior by most sharks is somewhat predictable. A shark preparing to attack swims with an exaggerated motion, its pectoral fins pointing down in contrast to the usual flared out position, and it swims in circles of decreasing radius around the prey. An attack may be heralded by unexpected acceleration, or other marked change in behavior, posture or swim patterns. Should surrounding schools of fish become unexplainably agitated, sharks may be in the area. Sharks are much faster and more powerful than any swimmer and all sharks must be treated with extreme respect and caution.

G-1.1.1 Types of Sharks.

- **White Shark (Figure G-1) -** This shark, also known as the great white shark, has widespread oceanic distribution, mostly

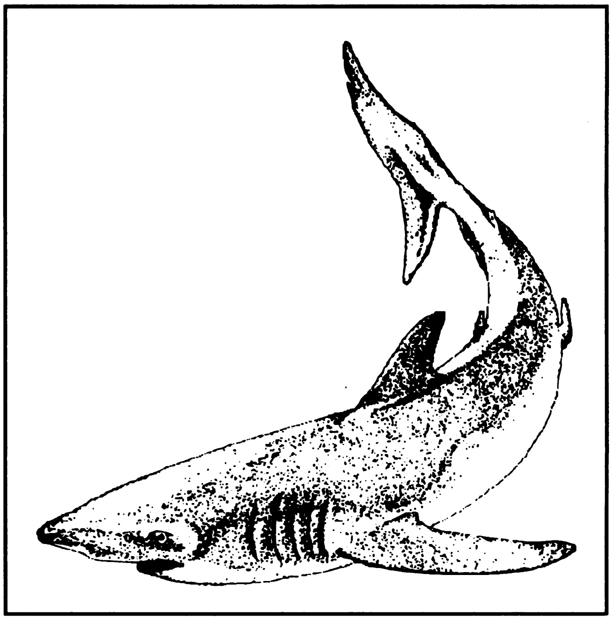


Figure G-1. White Shark.

in tropical and subtropical waters. It is especially numerous in Australian waters. Its color may be slate brown, slate blue, or dull gray, or may have an almost black dorsal surface with a dirty white underbelly. It may have small black spots with black fin tips. Larger white sharks are sometimes dun-colored or leaden white. It can grow up to an average of 20 to 25 feet long. This species is one of the most dangerous and has even been known to attack boats. It is aggressive, fast, and has a history of attacks on humans.

- **Mako Shark (Figure G-2) -** This oceanic species is found in both tropical waters and the warmer waters of the Atlantic and Pacific Oceans. It has prominent teeth and a slender form. Its color may be deep blue gray, bright blue, or deep blue on the dorsal surface with a white underbelly, with lengths up to 13 feet. It is savage, dangerous, and fast. It has a history of human attack. This species is classified as a game fish and also has been known to attack boats.

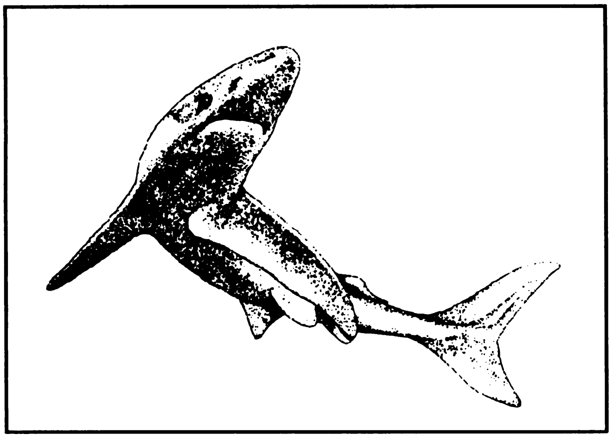


Figure G-2. Mako Shark.

- **Hammerhead Shark (Figure G-3) -** This species is found in both offshore and inshore waters. It is often seen swimming on the surface. Various species of the hammerhead are found in all tropical and warm waters of all oceans and seas. Easily recognized by the hammer-shaped head with eyes on the outer edges, it has an ashen-gray dorsal surface fading to white beneath, and may be up to 15 feet long. This shark is very aggressive and powerful and has been known to attack man.

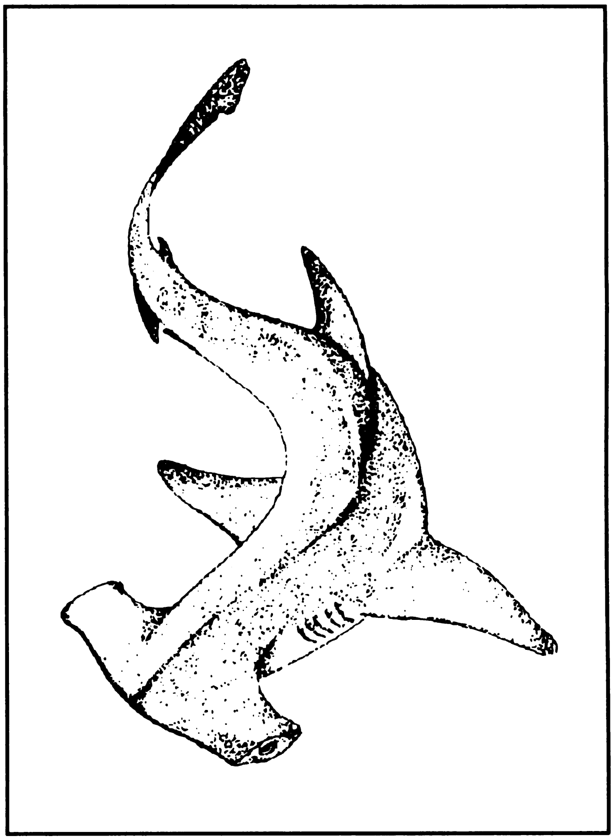


Figure G-3. Hammerhead Shark.

- **Tiger Shark -** This species is widespread through all tropical and warm belts of all oceans and is found in offshore and inshore waters. The tiger shark has prominent teeth, a short snout, sharply pointed tail, and is gray or grayish brown with a darker dorsal surface. Stripes are usually found only on the smaller sharks. It may grow up to 15 or 20 feet long. This species is a scavenger, but will attack humans.

- **White-Tipped Shark -** This shark is found in tropical and subtropical waters of the Atlantic and Mediterranean and along the Iberian Peninsula. It is also found in deep offshore waters. It has a short snout and a rounded dorsal fin. This species has a light gray-to-pale brown-to-slate blue dorsal surface and a whitish underbelly. There will be some spotting, and in some species, white tips on the fins. It can grow to an average of 13 feet. The white-tip shark is known to be fearless toward man and has a record of human attack.

- **Dusky Shark -** This shark is often found in shallow waters of warm temperature zones on both sides of the Atlantic. Its back and upper sides are usually leaden gray or bluish and its underbelly is white. This shark can grow up to 14 feet long. The dusky shark is unpredictable and fearless.

- **Bull Shark (Lake Nicaragua Shark, Ganges River Shark) -** The bull shark is found in coastal waters, but has been known to enter fresh waters. It is dark gray above, light below, and can grow up to 10 feet long. This species has some history of human attack and is unpredictable.

- **Lemon Shark -** The lemon shark is often found in inland waters, saltwater creeks, bays, and sounds. It may be active near piers in the inshore western Atlantic, the Carolinas, Northern Brazil, and tropical West Africa. The second dorsal fin is almost as large as the first. It has a broad, round snout and prominent teeth. Its coloring is yellowish brown above (occasionally dark blue-gray) with sides and underbelly yellow. It can grow up to 11 feet long. This species is unpredictable and has a history of human attack.

- **Sand Shark -** This collection of species lives on or near the sea floor. It inhabits the Mediterranean, West Africa's tropical zones, the Canaries and Cape Verde in the North Atlantic, South Africa, Western Atlantic from Maine to Florida, and Southern Brazil. There are similar species in Pacific Indian areas and the Argentine waters. Attaining lengths up to 10 feet, the sand shark has two equally-sized dorsal fins and prominent teeth. It is bright gray-brown above, dark along its back, pale on the sides, with gray white on its belly and the lower sides of its fins. The rear body is often marked with spots. This shark is fairly sluggish. The North American species are generally harmless, but the Indian Ocean species and other tropical species can be dangerous.

- **Porbeagle Shark -** This shark inhabits the continental waters of the North Atlantic, Mediterranean, Northwest Africa, North Sea, Northern British Isles, Atlantic coast of the U.S., and some Scandinavian regions. Its coloring is dark bluish gray above, and its lower sides are white. The anal fin is white or dusky with dusky tips on the pectoral fins. The Porbeagle has very prominent teeth and can grow up to 12 feet long. This shark is sluggish unless in pursuit.

G-1.1.2 Prevention. Preventive measures to be taken when swimming or diving in areas where sharks may be present are listed below:

- Avoid swimming or diving in murky waters, waters near deep troughs, or waters where animal by-products or garbage are dumped.

- Sharks generally feed at night. Swimming or diving in the evening in potentially shark-containing waters should be avoided.

- Explosions, lights, shiny objects, noise, or thrashing in the water can attract sharks.

- Since sharks are attracted to the scent of blood in the water, swimming with open wounds or speared fish should be avoided. Evidence of increased hazard to menstruating women swimming in waters where sharks are known to be present is inconclusive; however, women swimming during menstruation should use tampons.

- Do not dangle legs or arms in water.

- Do not throw waste or food refuse overboard if sharks are suspected in the area.

- Dark-colored clothing and equipment are preferred as sharks may be attracted to bright, flashing or colorful objects.

- Avoid swimming or diving alone.

- If diving in shark infested waters, one member of the dive pair should be on shark watch.

- If a shark is sighted, slow purposeful movements should be used. Often, remaining absolutely still is best. Making noise, blowing bubbles, etc., is of questionable value. Some noises may attract sharks.

- Attempts to kill or wound a shark are usually more dangerous than effective.

- The use of firearms by swim-sentries should be used with extreme caution because of the risk of injury to swimmers, divers, or other boats.

- If attacked, attempt to ward off shark in any manner, preferably with jabs to the eyes, gills, or, if possible, the underbelly. Blows to the snout may be ill advised because when the shark bites, its head is thrust up and its jaw is thrust forward. Consequently, a punch to the snout may miss the target and land in the shark's mouth. Often sharks can be shoved away with a shark billy, a speargun, or shot with a power-head or bang-stick. If air permits, divers may descend to the seabed or a rock cliff-face for protection. Never lose sight of an attacking shark.

- Current research on the development of shark repellants has revealed that certain fish secretions as well as some surfactants and industrial detergents are highly effective in repelling sharks. Future shark repellants may be based on these compounds.

G-1.1.3 First Aid and Treatment. Bites may result in a large amount of bleeding and tissue loss. Take immediate action to control bleeding using large gauze pressure bandages. Cover wounds with layers of compressive dressings preferably made with gauze, but easily made from shirts or towels and held in place by wrapping the wound tightly with gauze, torn clothing, towels, or sheets. Direct pressure with elevation or extreme compression on pressure points will control all but the most serious bleeding. The major pressure points are: the radial artery pulse point for the hand; above the elbow under the biceps muscle for the forearm (brachial artery); and the groin area with deep finger tip or heel of the hand pressure for bleeding from the leg (femoral artery). When bleeding cannot be controlled by direct pressure and elevation or pressure points, a tourniquet or ligature may be needed to save the victim's life even though there is the possibility of loss of the limb. Tourniquets are applied only as a last resort, and with only enough pressure to control bleeding. Do not remove the tourniquet. The tourniquet should be removed only by a physician in a hospital setting. Loosening of a tourniquet may cause further shock by releasing toxins into the circulatory system from the injured limb as well as continued blood loss.

Treat for shock by laying the patient down and elevating his feet (see Paragraph 8.2.4).

If medical personnel are available, begin intravenous (I.V.) Ringer's lactate or normal saline with a large bore cannula (16 or 18 ga). If blood loss has been extensive, several liters should be infused rapidly. The patient's color, pulse, and blood pressure should be used as a guide to the volume of fluid required. Maintain an airway and administer oxygen. Do not give fluids by mouth. If the patient's cardiovascular state is stable, narcotics may be administered in small doses for pain relief. Observe closely for evidence of depressed respirations due to the use of narcotics.

Initial stabilization procedures should include attention to the airway, breathing, and circulation, followed by a complete evaluation for multiple trauma.

Transport the victim to a medical facility as soon as possible. Reassure the patient.

Should a severed limb be retrieved, wrap it in bandages, moisten with saline, place in a plastic bag, and chill, but not in direct contact with ice. Transport the severed limb with the patient.

Clean and debride wounds as soon as possible in a hospital or controlled environment. Since shark teeth are cartilage, not bone, and may not appear on an X-ray, operative exploration should be performed to remove dislodged teeth.

Consider X-ray evaluation for potential bone damage due to crush injury. Severe crush injury may result in acute renal failure due to myoglobin released from injured muscle, causing the urine to be a smoky brown color. Monitor closely for kidney function and adjust I.V. fluid therapy appropriately.

Administer tetanus prophylaxis: Tetanus toxoid, 0.5 ml intramuscular (I.M.) and tetanus immune globulin, 250 to 400 units I.M.

Culture infected wounds for both aerobes and anaerobes before instituting broad spectrum antibiotic coverage; secondary infections with Clostridium and Vibrio species have been reported frequently.

Acute surgical repair, reconstructive surgery, and hyperbaric oxygen (HBO) adjuvant therapy improving tissue oxygenation may all be needed.

In cases of unexplained decrease in mental status or other neurological signs and symptoms following shark attack while diving, consider arterial gas embolism or decompression sickness as a possible cause.

G-1.2 Killer Whales (Figure G-4). Killer whales live in all oceans, both tropical and polar. This whale is a large mammal with a blunt, rounded snout and high black dorsal fin. The jet black head and back contrast sharply with the snowy-white underbelly. Usually, a white patch can be seen behind and above the eye.

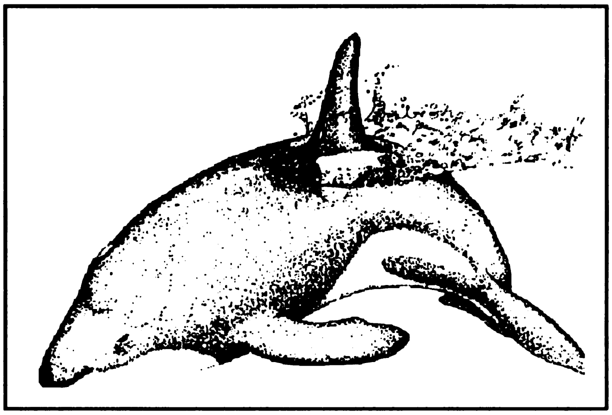


Figure G-4. Killer Whale.

The killer whale is usually observed in packs of 3 to 40 whales. It has powerful jaws, great weight, speed, and interlocking teeth. Because of its speed and carnivorous habits, this animal should be treated with great respect. There have been no recorded attacks on humans.

G-1.2.1 Prevention. When killer whales are spotted, all personnel should immediately leave the water. Extreme care should be taken on shore areas, piers, barges, ice floes, etc., when killer whales are in the area.

G-1.2.2 First Aid and Treatment. First aid and treatment would follow the same general principles as those used for a shark bite (Paragraph G-1.1.3).

G-1.3 Barracuda (Figure G-5).
Approximately 20 species of barracuda inhabit the oceans of the West Indies, the tropical waters from Brazil to Florida, and the Indo-Pacific oceans from the Red Sea to the Hawaiian Islands. The barracuda is a long, thin fish with prominent jaws and teeth, silver to blue in color, with a large head and a V-shaped tail. It may grow up to 10 feet long and is a fast swimmer, capable of striking rapidly and fiercely. It will follow swimmers but seldom attacks an underwater swimmer. It is known to attack surface swimmers and limbs dangling in the water. Barracuda wounds can be distinguished from those of a shark by the tooth pattern. A barracuda leaves straight or V-shaped wounds while those of a shark are curved like the shape of its jaws. Life threatening attacks by barracuda are rare.

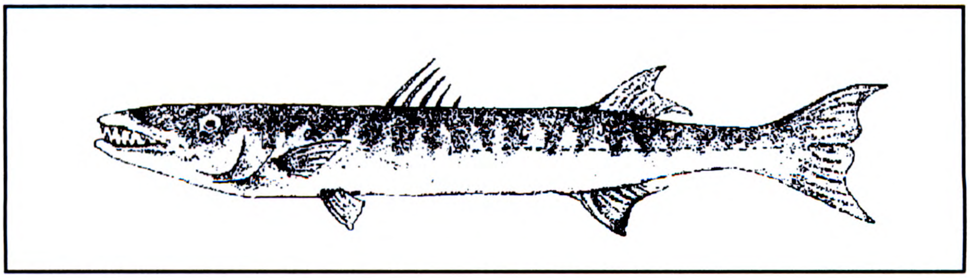


Figure G-5. Barracuda.

G-1.3.1 Prevention. Barracuda are attracted by any bright object. Avoid wearing shiny equipment or jewelry in waters when barracudas are likely to be present. Avoid carrying speared fish as barracuda will strike them. Avoid splashing or dangling limbs in barracuda infested waters.

G-1.3.2 First Aid and Treatment. First aid and treatment follow the same general principles as those used for shark bites (Paragraph G-1.1.3). Injuries are likely to be less severe than shark bite injuries.

G-1.4 Moray Eels (Figure G-6). While some temperate zone species of the Moray Eel are known, it primarily inhabits tropical and subtropical waters. It is a bottom dweller and is commonly found in holes, crevices, or under rocks and coral. It is snake-like in both appearance and movement, and has tough, leathery skin. It can grow to a length of 10 feet and has prominent teeth. A moray eel is extremely territorial and attacks frequently result from reaching into a crevice or hole occupied by the eel. It is a powerful and vicious

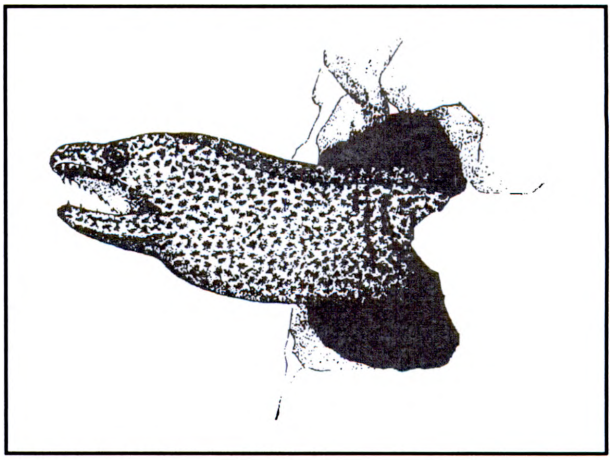


Figure G-6. Moray Eel.

biter and may be difficult to dislodge after a bite is initiated. Bites from moray eels may vary from multiple small puncture wounds to the tearing, jagged type with profuse bleeding if there has been a struggle. Injuries are usually inflicted on hands or forearms.

G-1.4.1 Prevention. Extreme care should be used when reaching into holes or crevices. Avoid provoking or attempting to dislodge an eel from its hole.

G-1.4.2 First Aid and Treatment. Primary first aid must stop the bleeding. Direct pressure and raising the injured extremity almost always controls bleeding.

Arrange for medical follow-up. Severe hand injuries should be evaluated immediately by a physician. Mild envenomation may occur from a toxin that is released from the palatine mucosa in the mouth of certain moray eels. The nature of this toxin is not known. Treatment is supportive. Follow principles of wound management and tetanus prophylaxis as in caring for shark bites. Antibiotic therapy should be instituted early. Immediate specialized care by a hand surgeon may be necessary for tendon and nerve repair of the hand to prevent permanent damage and loss of function of the hand.

G-1.5 Sea Lions. The sea lion inhabits the Pacific Ocean and is numerous on the West Coast of the United States. It resembles a large seal. Sea lions are normally harmless; however, during the breeding season, (October through December) large bull sea lions can become irritated and will nip at divers. Attempts by divers to handle these animals may result in bites. These bites appear similar to dog bites and are rarely severe.

G-1.5.1 Prevention. Divers should avoid these mammals when in the water.

G-1.5.2 First Aid and Treatment.

(1) Control local bleeding.

(2) Clean and debride wound.

(3) Administer tetanus prophylaxis as appropriate.

(4) Wound infections are common and prophylactic antibiotic therapy is advised.

G-2 VENOMOUS MARINE ANIMALS

G-2.1 Venomous Fish (Excluding Stonefish, Zebrafish, Scorpionfish). Identification of a fish following a sting is not always possible; however, symptoms and effects of venom do not vary greatly. Venomous fish are rarely aggressive and usually contact is made by accidentally stepping on or handling the fish. Dead fish spines remain toxic. Venom is generally heat labile and may be decomposed by hot water. Local symptoms following a sting may first include severe pain later combined with numbness or even hypersensitivity around the wound. The wound site may become cyanotic with surrounding tissue becoming pale and swollen. General symptoms may include nausea, vomiting, sweating, mild fever, respiratory distress, and collapse. The pain induced may seem disproportionately high to apparent severity of the injury. Medical personnel should be prepared for serious anaphylactic reactions from apparently minor stings or envenomation.

G-2.1.1 Types.

- **Catfish -** The catfish is found worldwide in fresh and salt water. Usually the lips of catfish are equipped with long barbels (whiskers); the skin is thick with no scales. Venom is in the spines of the dorsal and pectoral fins. No antivenom is available.

- **Weeverfish (Figure G-7) -** The weeverfish is found in the temperate zone from Europe to North Africa. It is small (up to 18 inches) and is usually found buried in the mud with only the head exposed. Spines on the cheeks and on the dorsal surface are used as a weapon in hunting for food. The weeverfish is aggressive and should not be handled under any circumstances. Even dead weeverfish can inflict a serious wound. No antivenom is available.

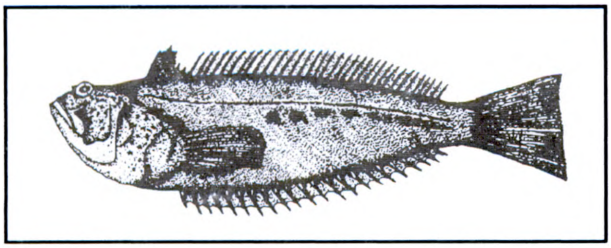


Figure G-7. Weeverfish.

- **Toadfish -** The toadfish can be found in warm coastal waters worldwide hiding in crevasses, under rocks, or lying completely buried under a few centimeters of sand. It is therefore advisable to shuffle your feet to scare off toadfish when walking in shallow water. It has a broad, depressed head, and large mouth. Both dorsal fin and gill cover have venomous spines. This fish can change color readily with excellent camouflaging.

- **Surgeonfish -** The surgeonfish is found along reefs in warm seas. It is short and vertical with full dorsal and anal fins. The sharp spine at the base of the tail fin can both envenom and cause severe lacerations.

- **Ratfish and Elephantfish -** One type of this fish is found in European waters and one type along the Pacific Coast of North America. Both have a rounded snout and a laterally compressed body tapering to a slender tail. At the first dorsal fin is the single large venom spine.

- **Rabbitfish -** The rabbitfish is found in the Indo-Pacific and is similar in appearance to the surgeonfish. Spines (a total of 24) are in dorsal, pelvic, and anal fins.

- **Spiny Dogfish (Spiny Shark) -** This fish is found in both the North Atlantic and North Pacific Oceans. This small slender shark prefers shallow, protected bays. A single spine that can be driven into flesh with a strong sudden jerk is located in front of each dorsal fin.

G-2.1.2 Prevention. Avoid handling suspected venomous fish. Venomous fish are often found in holes or crevices or lying well camouflaged on rocky bottoms. Divers should be alert for their presence and should take care to avoid them.

G-2.1.3 First Aid and Treatment.

(1) Get victim out of water; watch for fainting.

(2) Lay patient down and reassure.

(3) Observe for signs of shock.

(4) Wash wound with cold, salt water or sterile saline solution. Surgery may be re-

quired to open up the puncture wound. Suction is not effective to remove this toxin.

(5) Soak wound in hot water for 30 to 90 minutes. Heat may break down the venom. The water should be as hot as the victim can tolerate but not hotter than 122°F (50°C). Immersion in water above 122°F (50°C) for longer than a brief period may lead to scalding. Immersion in water up to 122°F (50°C) should therefore be brief and repeated as necessary. Use hot compresses if the wound is on the face. Adding magnesium sulfate (epsom salts) to the water offers no benefit.

(6) Calcium gluconate injections, diazepam, or methocarbamol may help to reduce muscle spasms. Infiltration of the wound with 0.5% to 2.0% xylocaine with no epinephrine is helpful in reducing pain. If xylocaine with epinephrine is mistakenly used, local necrosis may result from both the toxin and epinephrine present in the wound. Narcotics may also be needed to manage severe pain.

(7) Clean and debride wound. Spines and sheath frequently remain. Be sure to remove all of the sheath as it may continue to release venom.

(8) Tourniquets or ligatures are no longer advised. Use an antiseptic or antibiotic ointment and sterile dressing. Restrict movement of the extremity with immobilizing splints and cravats.

(9) Administer tetanus prophylaxis as appropriate.

(10) Treat prophylactically with topical antibiotic ointment. If delay in treatment has occured, it is recommended that the wound be cultured prior to administering systemic antibiotics.

G-2.2 Highly Toxic Fish (Stonefish, Zebrafish, Scorpionfish) (Figure G-8). Stings by stonefish, zebrafish, and scorpionfish have been known to cause fatalities. While many similarities exist between these fish and the venomous fish of the previous section, a separate section has been included because of the greater toxicity of their venom and the availability of an antivenin. The antivenin is specific for the stonefish but may have some beneficial effects against the scorpionfish and zebrafish. Local symptoms are similar to other fish envenomation except that pain is more severe and may persist for many days. Generalized symptoms are often present and may include respiratory failure and cardiovascular collapse. These fish are widely distributed in temperate and tropical seas and in some arctic waters. They are shallow water bottom dwellers. Stonefish and scorpionfish are flattened vertically, dark and mottled. Zebrafish are ornate and feathery in appearance with alternating patches of dark and light color.

G-2.2.1 Prevention. Prevention is the same as for venomous fish (Paragraph G-1.2.1.2).

G-2.2.2 First Aid and Treatment.

(1) Give the same first aid as that given for venomous fish (Paragraph G-2.1.3).

(2) Observe the patient carefully for the possible development of life-threatening complications. The venom is an unstable protein which acts as a myotoxin on skeletal, involuntary, and cardiac muscle. This may result in muscular paralysis, respiratory depression, peripheral vasodilation, shock, cardiac dysrhythmias, or cardiac arrest.

(3) Clean and debride wound.

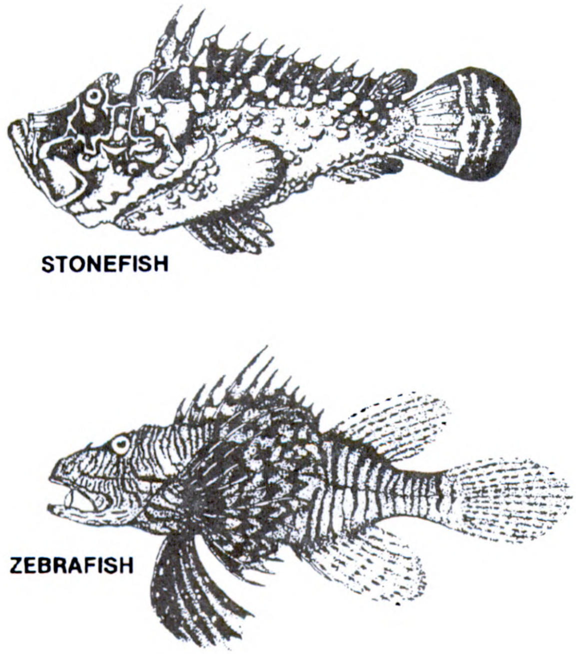


Figure G-8. Highly Toxic Fish.

(4) Antivenin is available from Commonwealth Serum Lab, Melbourne, Australia (see Reference 4 at end of this appendix for address and phone number). If antivenin is used, the directions regarding dosage and sensitivity testing on the accompanying package insert should be followed and the physician must be ready to treat for anaphylactic shock (severe allergic reaction). In brief, 1 or 2 punctures require 2,000 units (1 ampule); 3 to 4 punctures, 4,000 units (2 ampules); and 5 to 6 punctures, 6,000 units (3 ampules). Antivenin must be delivered by slow I.V. injection and the victim closely monitored for anaphylactic shock.

(5) Institute tetanus prophylaxis, analgesic therapy, and antibiotics as described for other fish stings.

G-2.3 Stingrays (Figure G-9). The stingray is common in all tropical, subtropical, warm, and temperate regions. It usually favors sheltered water and will burrow into sand with only eyes

Figure G-9. Stingray.

and tail exposed. It has a bat-like shape and a long tail. Approximately 1800 stingray attacks are reported annually in the U.S. Most attacks occur when waders inadvertently step on a ray, causing it to lash out defensively with its tail. The spine is located near the base of the tail. Wounds are either of the laceration or puncture type and are extremely painful. The wound appears swollen and pale with a blue rim. Secondary wound infections are common. Systemic symptoms may be present and can include fainting, nausea, vomiting, sweating, respiratory difficulty, and cardiovascular collapse.

G-2.3.1 Prevention. In shallow waters which favor stingray habitation, shuffle feet on the bottom and probe with a stick to alert the rays and chase them away.

G-2.3.2 First Aid and Treatment.

(1) Give the same first aid as that given for venomous fish (Paragraph G-2.1.3). No antivenin is available.

(2) Institute hot water therapy as described under fish envenomation.

(3) Clean and debride wound. Removal of the spine may additionally lacerate tissues due to retropointed barbs. Be sure to remove integumental sheath as it will continue to release toxin.

(4) Observe patient carefully for the possible development of life threatening complications. Symptoms can include cardiac dysrhythmias, hypotension, vomiting, diarrhea, sweating, muscle paralysis, respiratory depression, and cardiac arrest. Fatalities have been reported occasionally.

(5) Institute tetanus prophylaxis, analgesic therapy, and broad spectrum antibiotics as described for fish envenomation.

G-2.4 Coelenterates (Figure G-10).
Hazardous types of coelenterates include: Portuguese man-of-war, sea wasp or box jellyfish, sea nettle, sea blubber, sea anemone, and rosy anemone. Jellyfish vary widely in color (blue, green, pink, red, brown) or may be transparent. They appear to be balloon-like floats with tentacles dangling down into the water. The most common stinging injury is the jellyfish sting. Jellyfish can come into direct contact with a diver in virtually any oceanic region, worldwide. When this happens, the diver is exposed to literally thousands of minute stinging organs in the tentacles called nematocysts. Most jellyfish stings result only in painful local skin irritation. The sea wasp or box jellyfish and Portuguese man-of-war are the most dangerous types. The sea wasp or box jellyfish (found in the Indo-Pacific) can induce death within 10 minutes by cardiovascular collapse, respiratory failure, and muscular paralysis. Deaths from Portuguese man-of-war stings have also been reported.

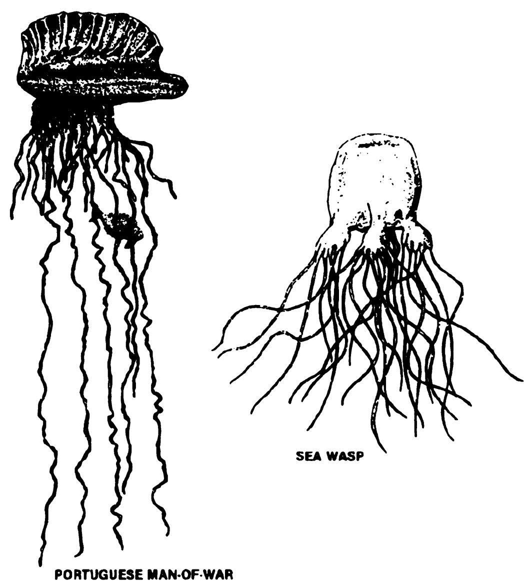


Figure G-10. Coelenterates.

Even though intoxication from ingesting poisonous sea anemones is rare, sea anemones must not be eaten.

G-2.4.1 Prevention. Do not handle jellyfish. Beached or apparently dead specimens may still be able to sting. Even towels or clothing contaminated with the stinging nematocysts may cause stinging months later.

In some species of jellyfish, tentacles may trail for great distances horizontally or vertically in the water, and are not easily seen by the diver. Swimmers and divers should avoid close proximity to jellyfish to avoid contacting their tentacles, especially when near the surface.

Wet suits, body shells, or protective clothing should be worn when diving in waters where jellyfish are abundant. Petroleum jelly applied to exposed skin (e.g., around the mouth) helps to prevent stinging, but caution should be used since petroleum jelly can deteriorate rubber products.

G-2.4.2 First Aid and Treatment. Without rubbing, gently remove any remaining tentacles using a towel or clothing. For preventing any further discharge of the stinging nematocysts, use vinegar (dilute acetic acid) or a 3 to 10% solution of acetic acid. An aqueous solution of 20% aluminum sulfate and 11% surfactant (detergent) is moderately effective but vinegar works better. Do not use alcohol or preparations containing alcohol. Methylated spirits or methanol, 100% alcohol, and alcohol plus seawater mixtures have all been demonstrated to cause a massive discharge of the nematocysts. In addition, these compounds may also worsen the skin inflammatory reaction. Picric acid, human urine, as well as fresh water also have been found to either be ineffective or even to discharge nematocysts and should not be used. Rubbing sand or applying papain-containing meat tenderizer is ineffective and may lead to further nematocysts discharge and should not be used. It has been suggested that isopropyl (rubbing) alcohol may be effective. It should only be tried if vinegar or dilute acetic acid is not available.

Symptomatic treatment can include topical steroid therapy, anesthetic ointment (xylocaine, 2%) antihistamine lotion, systemic antihistamines, or analgesics. Benzocaine topical anesthetic preparations should not be used as they may cause sensitization and later skin reactions.

Anaphylaxis (severe allergic reaction) may result from jellyfish stings.

Antivenin is available to neutralize the effects of the sea wasp or box jellyfish (Chironex fleckeri). The antivenin should be administered slowly through an I.V., with an infusion technique if possible. I.M. injection should be administered only if the I.V. method is not feasible. One container (vial) of sea wasp antivenin should be used by the I.V. route and three containers if injected by the I.M. route. Each container of sea wasp antivenin is 20,000 units and is to be kept refrigerated, not frozen, at 36-50°F (2-10°C). Sensitivity reaction to the antivenin should be treated with a subcutaneous injection of epinephrine (0.3cc of 1:1,000 dilution), corticosteroids and antihistamines. Treat any hypotension (severely low blood pressure) with I.V. volume expanders and pressor medication as necessary. The antivenin may be obtained from the Commonwealth Serum Laboratories, Melbourne, Australia (see Reference 4 for address and phone number).

G-2.5 Coral. Coral, a porous, rock-like formation, is found in tropical and subtropical waters. Coral is extremely sharp, and the most delicate coral is often the most dangerous because of their razor sharp edges. Coral cuts, while usually fairly superficial, take a long time to heal and can cause temporary disability. The smallest cut, if left untreated, can develop into a skin ulcer. Secondary infections often occur and may be recognized by the presence of a red and tender area surrounding the wound. All coral cuts should receive medical attention. Some varieties of coral can actually sting a diver since coral is a coelenterate like jellyfish. Some of the soft coral of the genus Palythoa have been found recently to contain the deadliest poison known to man. This poison is found within the body of the organism and not in the stinging nematocysts. The slime of this coral may cause a serious skin reaction (dermatitis) or even be fatal if exposed to an open wound. No antidote is known.

G-2.5.1 Prevention. Extreme care should be used when working near coral. Often coral is located in a reef formation subjected to heavy surface water action, surface current, and bottom current. Surge also develops in reef areas. For this reason, it is easy for the unknowing diver to be swept or tumbled across coral with serious consequences. Be prepared.

Coral should not be handled with bare hands. Feet should be protected with booties, coral shoes, or tennis shoes.

Wet suits and protective clothing, especially gloves (neoprene or heavy work gloves), should be worn when near coral.

G-2.5.2 First Aid and Treatment.

(1) Control local bleeding.

(2) Promptly clean with hydrogen peroxide or 10% povidone-iodine solution and debride the wound removing all foreign particles.

(3) Cover with a clean dressing.

(4) Administer tetanus prophylaxis as appropriate.

(5) Topical antibiotic ointment has been proven very effective in preventing secondary infection. Stinging coral wounds may require symptomatic management such as topical steroid therapy, systemic antihistamines, and analgesics. In severe cases, restrict the patient to bedrest with elevation of the extremity, wet-to-dry dressings and systemic antibiotics. Systemic steroids may be needed to manage the inflammatory reaction due to a combination of trauma and dermatitis.

G-2.6 Octopuses (Figure G-11). The octopus inhabits tropical and temperate oceans. Species vary depending on region. It has a large sac surrounded by 8 to 10 tentacles. The head sac is large with well-developed eyes and horny jaws on the mouth. Movement is made by jet action produced by expelling water from the mantle cavity through the siphon. The octopus will hide in caves, crevices, and shells. It possesses a well-developed venom apparatus in its salivary glands, and stings by biting. Most species of octopus found in the U.S. are harmless. The blue-ringed octopus common in Australian and Indo-Pacific waters may inflict fatal bites. The venom of the blue-ringed octopus is a neuromuscular blocker called tetrodotoxin and is also found in Puffer (Fugu) fish. Envenomation from the bite of a blue-ringed octopus may lead to muscular paralysis, vomiting, respira-

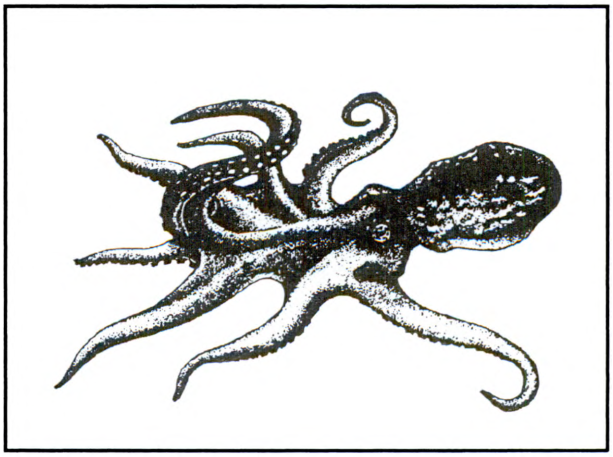


Figure G-11. Octopus.

tory difficulty, visual disturbances, and cardiovascular collapse. Octopus bites consist of two small punctures. A burning or tingling sensation results and may soon spread. Swelling, redness, and inflammation are common. Bleeding may be severe and the clotting ability of the blood is often retarded by the action of an anticoagulant in the venom.

G-2.6.1 Prevention. Extreme care should be used when reaching into caves and crevices. Regardless of size, an octopus should be handled carefully with gloves. It is ill advised to spear an octopus, especially the large octopuses found off the coast of the Northwestern United States, due to the risk of being engtangled by the octopus' tenacles. If killing an octopus becomes necessary, stabbing it between the eyes is recommended.

G-2.6.2 First Aid and Treatment.

(1) Control local bleeding.

(2) Clean and debride the wound and cover with a clean dressing.

(3) For suspected blue-ringed octopus bites, a loose constrictive band should not be applied. Apply direct pressure with a pressure bandage and immobilize the extremity in a position that is lower than the heart using splints and elastic bandages.

(4) Be prepared to administer mouth-to-mouth resuscitation and cardiopulmonary resuscitation if necessary.

(5) Blue-ringed octopus venom is heat stable and acts as a neurotoxin and neuromuscular blocking agent. Venom is not affected by hot water therapy. No antivenin is available.

(6) Medical therapy for blue-ringed octopus bites is directed toward management of paralytic, cardiovascular, and respiratory complications. Respiratory arrest is common and intubation with mechanical ventilation may be required. Duration of paralysis is between 4 and 12 hours. Reassure the patient.

(7) Administer tetanus prophylaxis as appropriate.

G-2.7 Segmented Worms (Annelida) (Examples: Bloodworm, Bristleworm). This invertebrate type varies according to region and is found in warm, tropical, or temperate zones. It is usually found under rocks or coral and is especially common in the tropical Pacific, Bahamas, Florida Keys, and Gulf of Mexico. Annelida have long, segmented bodies with stinging bristle-like structures on each segment. Some species have jaws and will also inflict a very painful bite. Venom causes swelling and pain.

G-2.7.1 Prevention. Wear lightweight, cotton gloves to protect against bloodworms, but wear rubber or heavy leather gloves for protection against bristleworms.

G-2.7.2 First Aid and Treatment.

(1) Remove bristles with a very sticky tape such as adhesive tape or duct tape. Topical application of vinegar will lessen pain.

(2) Treatment is directed toward relief of symptoms and may include topical steroid therapy, systemic antihistamines, and analgesics.

(3) Wound infection can occur but can be easily prevented by cleaning the skin using an antiseptic solution of 10% povidone-iodine and topical antibiotic ointment. Systemic antibiotics may be needed for established secondary infec-

tions that first need culturing, aerobically and anaerobically.

G-2.8 Sea Urchins. There are various species of sea urchins with widespread distribution. Each species has a radial shape and long spines. Penetration of the sea urchin spine can cause intense local pain due to a venom in the spine or from another type of stinging organ called the globiferous pedicellariae. Numbness, generalized weakness, paresthesias, nausea, vomiting and cardiac dysrhythmias have been reported.

G-2.8.1 Prevention. Avoid contact with sea urchins. Even the short-spined sea urchin can inflict its venom via the pedicellariae stinging organs. Protective footwear and gloves are recommended. Spines can penetrate wetsuits, booties, and tennis shoes.

G-2.8.2 First Aid and Treatment.

(1) Remove large spine fragments gently, being very careful not to break them into small fragments that remain in the wound.

(2) Bathe the wound in vinegar or isopropyl alcohol. Soaking the injured extremity in hot water up to 122°F (50°C) may help. Caution should be used to prevent scalding the skin which can easily occur after a brief period in water above 122°F (50°C).

(3) Clean and debride the wound. Topical antibiotic ointment should be used to prevent infection. Culture both aerobically and anaerobically before administering systemic antibiotics for established secondary infections.

(4) Remove as much of the spine as possible. Some small fragments may be absorbed by the body. Surgical removal, preferably with a dissecting microscope, may be required when spines are near nerves and joints. X-rays may be required to locate these spines. Spines can form granulomas months later and may even migrate to other sites.

(5) Allergic reaction and bronchospasm can be controlled with subcutaneous epinephrine (0.3 cc of 1:1,000 dilution) and by using systemic antihistamines. There are no specific antivenins available.

(6) Administer tetanus prophylaxis as appropriate.

(7) Get medical attention for deep wounds.

G-2.9 Cone Shells (Figure G-12). The cone shell is widely distributed in all regions and is usually found under rocks, coral, or crawling along sand. The shell is most often symmetrical in a spiral coil, colorful, with a distinct head, one to two pairs of tentacles, two eyes, and a large flattened foot on the body. A cone shell sting should be considered as severe as a poisonous

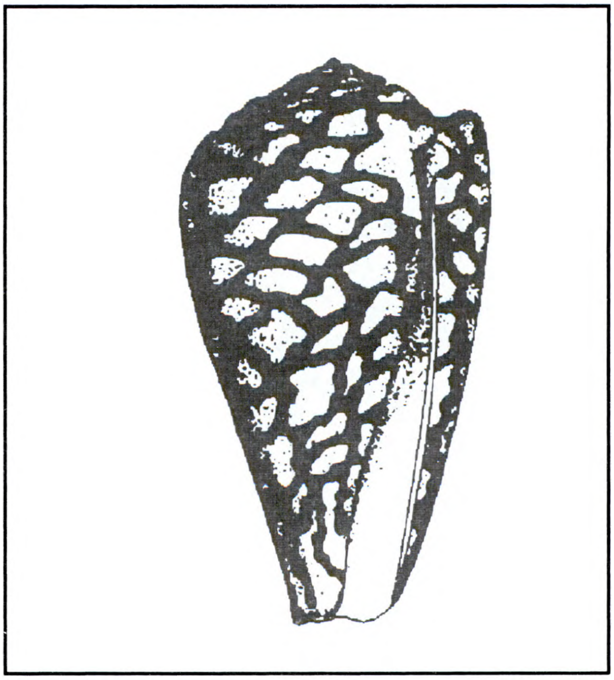


Figure G-12. Cone Shell.

snake bite. It has a highly developed venom apparatus: venom is contained in darts inside the proboscis which extrudes from the narrow end but is able to reach most of the shell. Cone shell stings are followed by a stinging or burning sensation at the site of the wound. Numbness and tingling begin at the site of the wound and may spread to the rest of the body; involvement of the mouth and lips is severe. Other symptoms may include muscular paralysis, difficulty with swallowing and speech, visual disturbances, and respiratory distress.

G-2.9.1 Prevention. Avoid handling cone shells. Venom can be injected through clothing and gloves.

G-2.9.2 First Aid and Treatment.

(1) Lay the patient down.

(2) Do not apply a loose constricting band or ligature. Direct pressure with a pressure bandage and immobilization in a position lower than the level of the heart using splints and elastic bandages is recommended.

(3) Some authorities recommend incision of the wound and removal of the venom by suction although this is controversial. However, general agreement is that if an incision is to be made, the cuts should be small (one centimeter), linear, and penetrate no deeper than the subcutaneous tissue. The incision and suction should only be performed if it is possible to do so within two minutes of the sting. Otherwise, the procedure may be ineffective. Incision and suction by inexperienced personnel has resulted in inadvertent disruption of nerves, tendons, and blood vessels.

(4) Transport the patient to a medical facility ensuring that the patient is breathing adequately. Be prepared to administer mouth-to- mouth resuscitation if necessary.

(5) Cone shell venom results in paralysis or paresis of skeletal muscle, with or without myalgia. Symptoms develop within minutes of the sting and effects can last up to 24 hours.

(6) No antivenin is available.

(7) Respiratory distress may occur due to neuromuscular block. Patient should be admitted to a medical facility and monitored closely for respiratory or cardiovascular complications. Treat as symptoms develop.

(8) Local anesthetic with no epinephrine may be injected into the site of the wound if pain is severe. Analgesics which produce respiratory depression should be used with caution.

(9) Management of severe stings is supportive. Respiration may need to be supported with intubation and mechanical ventilation.

(10) Administer tetanus prophylaxis as appropriate.

G-2.10 Sea Snakes (Figure G-13). The sea snake is an air breathing reptile which has adapted to its aquatic environment by developing a paddle tail. It injects a poison that has 2 to 10 times the toxicity of cobra venom. The bites usually appear as 4 puncture marks but may range from 1 to 20 punctures. Teeth may remain in the wound. The neurotoxin poison is a heat-stable nonenzymatic protein; hence, sea snake bites should not be immersed in hot water as with venomous fish stings.

Sea snakes inhabit the Indo-Pacific area and the

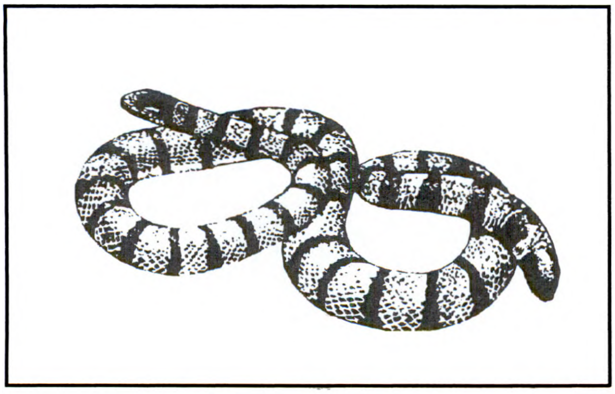


Figure G-13. Sea Snake.

Red Sea, and have been seen 150 miles from land. The most dangerous areas in which to swim are river mouths where sea snakes are more numerous and the water more turbid. The sea snake is a true snake, usually three to four feet in length but may reach nine feet. It is generally banded. The sea snake is curious and is often attracted by divers and usually is not aggressive except during its mating season. Due to its small jaws, bites often do not result in envenomation. Sea snake bites characteristically produce little pain and there is usually a latent period of 10 minutes to as long as several hours before the development of generalized symptoms: muscle aching and stiffness, thick tongue sensation, progressive paralysis, nausea, vomiting, difficulty with speech and swallowing, respiratory distress and failure, plus smoky-colored urine from myoglobinuria which may go on to kidney failure.

G-2.10.1 Prevention. Wet suits or protective clothing, especially gloves, may provide substantial protection against bites and should be worn when diving in waters where sea snakes are abundant. Also, shoes should be worn when walking where sea snakes are known to exist, including in the vicinity of fishing operations.

Do not handle sea snakes. Bites often occur on the hands of fishermen attempting to remove snakes from nets.

G-2.10.2 First Aid and Treatment.

(1) Keep victim still.

(2) Do not apply a loose constricting band or tourniquet. Apply direct pressure using a compression bandage and immobilize the extremity in the dependent position with splints and elastic bandages. This prevents spreading of the neurotoxin through the lymphatic circulation.

(3) Incise and apply suction (see cone shell stings, Paragraph G-2.9.2).

(4) Transport all sea snake bite victims to a medical facility as soon as possible, regardless of their current symptoms.

(5) Watch to ensure that the patient is breathing adequately. Be prepared to administer mouth-to-mouth resuscitation or cardiopulmonary resuscitation if required.

(6) The venom is a heat-stable protein which blocks neuromuscular transmission. Myonecrosis with resultant myoglobinuria and renal damage are often seen. Hypotension may develop.

(7) Respiratory arrest may result from generalized muscular paralysis; intubation and mechanical ventilation may be required.

(8) Renal function should be closely monitored and peritoneal or hemodialysis may be needed. Alkalinization of urine with sufficient I.V. fluids will promote myoglobin excretion. Monitor renal function and fluid balance anticipating acute renal failure.

(9) Vital signs should be monitored closely. Cardiovascular support plus oxygen and I.V. fluids may be required.

(10) Because of the possibility of delayed symptoms, all sea snake bite victims should be observed for at least 12 hours.

(11) If symptoms of envenomation occur within one hour, antivenin should be administered as soon as possible. In a seriously envenomated patient, antivenin therapy may be helpful even after a significant delay. Antivenin is available from the Commonwealth Serum Lab in Melbourne, Australia (see Reference D of this appendix for address and phone number). If specific antivenin is not available, polyvalent land snake antivenin (with a tiger snake or krait Elapidae component) may be substituted. If antivenin is used, the directions regarding dosage and sensitivity testing on the accompanying package insert should be followed and the physician must be ready to treat for anaphylaxis (severe allergic reaction). Infusion by the I.V. method, or closely monitored drip over a period of one hour, is recommended.

(12) Administer tetanus prophylaxis as appropriate.

G-2.11 Sponges. Sponges are composed of minute multicellular animals with spicules of silica or calcium carbonate embedded in a fibrous skeleton. Exposure of skin to the chemical irritants on the surface of certain sponges or exposure to the minute sharp spicules can cause a painful skin condition called dermatitis.

G-2.11.1 Prevention. Avoid contact with sponges and wear gloves when handling live sponges.

G-2.11.2 First Aid and Treatment.

(1) Adhesive or duct tape can effectively remove the sponge spicules.

(2) Vinegar or 3 percent to 10 percent acetic acid should be applied with saturated compresses as sponges may be secondarily inhabited by stinging coelenterates.

(3) Antihistamine lotion (diphenhydramine) and later, a topical steroid (hydrocortisone) may be applied to reduce the early inflammatory reaction.

(4) Antibiotic ointment is effective in reducing the chance of a secondary infection.

G-3 POISONOUS MARINE ANIMALS

G-3.1 Ciguatera Fish Poisoning. Ciguatera poisoning is fish poisoning caused by eating the flesh of a fish that has eaten a toxin-producing microorganism, the dinoflagellate, *Gambierdiscus toxicus*. The poisoning is common in reef fish between latitudes 35°N and 35°S around tropical islands or tropical and semitropical shorelines in Southern Florida, the Caribbean, the West Indies, and the Pacific and Indian Oceans. Fish and marine animals affected include barracuda, red snapper, grouper, sea bass, amberjack, parrot fish and the moray eel. Incidence is unpredictable and dependent on environmental changes that affect the level of dinoflagellates. The toxin is heat stable, tasteless, odorless and is not destroyed by cooking or gastric acid. Symptoms may begin immediately or within several hours of ingestion and may include nausea, vomiting, diarrhea, itching and muscle weakness, aches and spasms. Neurological symptoms may include pain, ataxia (stumbling gait), paresthesias (tingling), and circumoral parasthesias (numbness around the mouth). Sensory reversal of hot and cold sensation when touching or eating objects of extreme temperatures may occur. In severe cases, respiratory failure and cardiovascular collapse may occur. Pruritus (itching) is characteristically made worse by alcohol ingestion. Gastrointestinal symptoms usually disappear within 24 to 72 hours. Although complete recovery will occur in the majority of cases, neurological symptoms may persist for months or years. Signs and symptoms of ciguatera fish poisoning may be misdiagnosed as decompression sickness or contact dermatitis from unseen fire coral or jellyfish. Because of rapid modern travel and refrigeration, ciguatera poisoning may occur far from endemic areas with international travelers or unsuspecting restaurant patrons.

G-3.1.1 Prevention. Never eat the liver, viscera or roe (eggs) of tropical fish. Unusually large fish of a species should be suspected. When traveling, consult natives concerning fish poisoning from local fish, although such information may not always be reliable. A radioimmunoassay has been developed to test fish flesh for the presence of the toxin, and soon may be generally available.

G-3.1.2 First Aid and Treatment.

(1) Treatment is largely supportive and symptomatic. If the time since suspected ingestion of the fish is brief, and the victim is fully conscious, induce vomiting (syrup of Ipecac) and administer purgatives (cathartics, laxatives) to speed the elimination of undigested fish.

(2) In addition to the symptoms described above, other complications which may require treatment include hypotension and cardiac dysrhythmias.

(3) Antiemetics and antidiarrheal agents may be required if gastrointestinal symptoms are severe. Atropine may be needed to control bradycardia. I.V. fluids may be needed to control hypotension. Calcium gluconate, diazepam, and methocarbamol can be given for muscle spasm.

(4) Amytriptyline has been used successfully to resolve neurological symptoms such as depression.

(5) Cool showers may induce pruritus (itching).

G-3.2 Scombroid Fish Poisoning. Unlike ciguatera fish poisoning (see Paragraph G-1.3.1) where actual toxin is already concentrated in the flesh of the fish, scombroid fish poisoning occurs from different types of fish that have not been promptly cooled or prepared for immediate consumption. Typical fish causing scombroid poisoning include tuna, skipjack, mackerel, bonito, dolphin fish, mahimahi (Pacific dolphin) and bluefish. Fish that cause scombroid poisoning are found in both tropical and temperate waters. A rapid bacterial production of histamine and saurine (a histamine-like compound) produce the symptoms of a histamine reaction: nausea, abdominal pain, vomiting, facial flushing, urticaria (hives), headache, pruritus (itching), bronchospasm, and a burning or itching sensation in the mouth. Symptoms may begin one hour after ingestion and last 8 to 12 hours. Death is rare.

G-3.2.1 Prevention. Immediately clean the fish and preserve by rapid chilling. Do not eat any fish that has been left in the sun or in the heat longer than two hours.

G-3.2.2 First Aid and Treatment. Oral antihistamine, (e.g. diphenhydramine, cimetidine), epinephrine (given subcutaneously) and steroids are to be given as needed.

G-3.3 Puffer (Fugu) Fish Poisoning. An extremely potent neurotoxin called tetrodotoxin is found in the viscera, gonads, liver, and skin of a variety of fish including the puffer fish, porcupine fish, and ocean sunfish. Puffer fish, also called blow fish, toad fish, balloon fish, and called Fugu in Japanese, are found primarily in the tropics but also in temperate waters of the coastal United States, Africa, South America, Asia and the Mediterranean.

Puffer fish is considered a delicacy in Japan where it is thinly sliced and eaten as sashimi. Licensed chiefs are trained to select those puffer fish least likely to be poisonous and also to avoid contact with the visceral organs known to concentrate the poison.

The first sign of poisoning is usually tingling around the mouth which spreads to the extremities and may lead to a bodywide numbness. Neurological findings may progress to stumbling gait (ataxia), generalized weakness, and paralysis. The victim, though paralyzed, remains conscious until death occurs by respiratory arrest.

G-3.3.1 Prevention. Avoid eating puffer fish. Cooking the poisonous flesh will not destroy the toxin.

G-3.3.2 First Aid and Treatment.

(1) Provide supportive care with airway management, and monitor breathing and circulation.

(2) Monitor renal function.

(3) Monitor and treat cardiac dysrhythmias.

G-3.4 Paralytic Shellfish Poisoning (PSP) (Red Tide). Paralytic shellfish poisoning (PSP) is due to mollusks (bivalves) such as clams, oysters and mussels ingesting dinoflagellates that produce a neurotoxin which then affects man. Proliferation of these dinoflagellates during the warmest months of the year produce a characteristic red tide. However, some dinoflagellate blooms are colorless, so that poisonous mollusks may be unknowingly consumed. Local public health authorities must monitor both seawater and shellfish samples to detect the toxin. Poisonous shellfish cannot be detected by appearance, smell, discoloration of either a silver object or a garlic placed in the cooking water. Also, poisonous shellfish can be found in either low or high tidal zones. The toxic varieties of dinoflagellates are common in the following areas: Northwestern United States and Canada, Alaska, part of western South America, Northeastern United States, the North Sea European countries, and in the Gulf Coast area of the United States. One other type of dinoflagellate, though not toxic if ingested, may lead to eye and respiratory tract irritation from shoreline exposure to a dinoflagellate bloom that becomes aerosolized by wave action and wind.

Symptoms of bodywide PSP include circumoral paresthesias (tingling around the mouth) which spreads to the extremities and may progress to muscle weakness, ataxia, salivation, intense thirst, and difficulty in swallowing. Gastrointestinal symptoms are not common. Death, although uncommon, is due to respiratory arrest. Symptoms begin 30 minutes after ingestion and may last for many weeks. Gastrointestinal illness occuring several hours after ingestion is most likely due to a bacterial contamination of the shellfish (see Paragraph G-3.5). Allergic reactions such as urticaria (hives), pruritus (itching), dryness or scratching sensation in the throat, swollen tongue, and bronchospasm may also be an individual hypersensitivity to a specific shellfish, and not PSP.

G-3.4.1 Prevention. Since this dinoflagellate is heat stable, cooking does not prevent poisoning. The broth or bouillon in which the shellfish is boiled is especially dangerous since the poison is water soluble and will be found concentrated in the broth.

G-3.4.2 First Aid and Treatment.

(1) No antidote is known. If the victim is fully conscious, induce vomiting with 30cc (2 tablespoons) of syrup of Ipecac. Lavaging the stomach with alkaline fluids (solution of baking soda) may be helpful since the poison is acid stable.

(2) Provide supportive treatment with close observation and advanced life support if needed until the illness resolves. The poisoning is also related to the quantity of poisonous shellfish consumed and the concentration of the dinoflagellate contamination.

G-3.5 Bacterial and Viral Diseases from Shellfish. Large outbreaks of typhoid fever and other diarrheal diseases caused by the genus Vibrio have been traced to consuming contaminated raw oysters and inadequately cooked crabs and shrimp. Diarrheal stool samples from patients suspected of having bacterial and viral diseases from shellfish should be placed on a special growth medium (thiosulfate-citrate-bile salts-sucrose (TCBS) agar) to specifically grow Vibrio species, with isolates being sent to reference laboratories for confirmation.

G-3.5.1 Prevention. To avoid bacterial or viral disease (e.g., Hepatitus A or Norwalk viral gastroenteritis) that is associated with oysters, clams, and other shellfish, an individual should eat only thoroughly cooked shellfish. It has been proven that eating raw shellfish (mollusks) presents a definite risk of contracting disease.

G-3.5.2 First Aid and Treatment.

(1) Provide supportive care with attention to maintaining fluid intake by mouth or I.V. if necessary.

(2) Consult medical personnel for treatment of the various Vibrio species that may be suspected.

G-3.6 Sea Cucumbers. The sea cucumber is frequently eaten in some parts of the world where it is sold as Trepang or Beche-de-mer. It is boiled and then dried in the sun or smoked. Contact with the liquid ejected from the visceral cavity of some sea cucumber species may result in a severe skin reaction (dermatitis) or even blindness. Intoxication from sea cucumber ingestion is rare.

G-3.6.1 Prevention. Local inhabitants can advise about the edibility of sea cucumbers in that region. However, this information may not be reliable. Avoid contact with visceral juices.

G-3.6.2 First Aid and Treatment. Because no antidote is known, treatment is only symptomatic. Skin irritation may be treated like jellyfish stings (Paragraph G-2.4.2).

G-3.7 Parasitic Infestation. Parasitic infestations can be of two types: superficial and flesh. Superficial parasites burrow in the flesh of the fish and are easily seen and removed. These may include fish lice, anchor worms, and leeches. Flesh parasites can be either encysted or free in the muscle, entrails, and gills of the fish. These parasites may include roundworms, tapeworms, and flukes. If the fish is inadequately cooked, these parasites can be passed on to man. Table G-1 lists common marine parasites and their hosts.

G-3.7.1 Prevention. Avoid eating raw fish. Prepare all fish by thorough cooking or hot-smoking. When cleaning fish, look for mealy or encysted areas in the flesh; cut out and discard any cyst or suspicious areas. Remove all superficial parasites. Never eat the entrails or viscera of any fish.

G-4 REFERENCES FOR ADDITIONAL INFORMATION

(1) *Prevention and Treatment of Dangerous Marine Animal Injuries*, a publication by International Biotoxicological Centre, World Life Research Institute, Colton, CA; November 1982; P.S. Auerbach and B.W. Halstead

(2) *Management of Wilderness and Environmental Emergencies*, Macmillan Pub-

Table G-1. Common Marine Parasites and Their Hosts.

Fish	Common Parasite	Season	Human Effect
Bluefish	Gill Parasites	Year-round	None known
Striped Drum	Tapeworm	Summer	Infests digestive tract
Flounder	Roundworm	Summer	Enteritis and Meningioencephalitis
Grouper	Roundworm	Summer	Enteritis and Meningioencephalitis
Mackerel	Tapeworm	Summer	Infests digestive tract
Mullet	Liver, Blood Flukes	Year-round	Infests liver, blood
Sea Trout	Tapeworm	Summer	Infests digestive tract
Snapper	Leeches	Year-round	None known
Snook	Fish Lice	Year-round	None known

lishing Co., New York, N. Y., 1983. Eds. P.S. Auerbach and E.C. Greehr.

(3) *The Life of Sharks*, Columbia University Press, New York 1971. P. Budkur.

(4) Commonwealth Serum Laboratories, 45 Poplar Road, Parkville, Melbourne, Victoria, Australia; Telephone Number: 011-61-3-389-1911, Telex AA-32789

(5) *Sharks*. Doubleday, Garden City, N.Y., 1970. J. Y. Cousteau.

(6) *Fish and Shellfish Acquired Diseases*. American Family Physician. Vol 24: pp. 103-108, 1981. M. L. Dembert, K. Strosahl and R. L. Bumgarner.

(7) *Consumption of Raw Shellfish - Is the Risk Now Unacceptable?* New England Journal of Medicine. Vol 314: pp.707-708, 1986. H. L. DuPont.

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(10) *Principles and Practice of Emergency Medicine,* W. B. Saunders Co., Philadelphia, PA; 1978, pp. 812-815; G. Schwartz, P. Sofar, J. Stone, P. Starey, and D. Wagner

(11) *Dangerous Marine Creatures,* Reed Book Ptg., Ltd., 2 Aquatic Drive, French's Forest, NSW 20806 Austrailia. C. Edmonds.

(12) *A Medical Guide to Hazardous Marine Life,* Second Edition, Mosby Yearbook, 1991, P.S. Auerbach.

APPENDIX H

NEUROLOGICAL EXAMINATION

H-1 INTRODUCTION

This appendix provides guidance on evaluating diving accidents prior to treatment. It is divided into two parts. Part A is a guide aimed at non-medical personnel for recording essential details and conducting a neurological examination. Part B is a form designed for a more thorough and detailed recording format for medical personnel. Copies of these forms should be readily available for use if needed. While their use is not mandatory, they provide a useful aid for gathering information.

H-2 INITIAL ASSESSMENT OF DIVING INJURIES

Whether using the form in Part A or Part B, the initial assessment must gather the necessary information for proper evaluation of the accident.

When a diver reports with a medical complaint, a history of the case shall be compiled. This history should include facts ranging from the dive profile to progression of the medical problem. If available, review the diver's Health Record and completed Diving Chart or Diving Log to aid in the examination. A few key questions can help determine a preliminary diagnosis and any immediate treatment needed. If the preliminary diagnosis shows the need for immediate recompression, proceed with recompression. Complete the examination when the patient stabilizes at treatment depth. Typical questioning should include the following:

(1) What is the problem/symptom? If the only symptom is pain:

a. Describe the pain:

- sharp
- dull
- throbbing

b. Is the pain localized, or hard to pinpoint?

(2) Has the patient made a dive within the last 12 hours?

(3) What was the dive profile?

a. What was the depth of the dive?

b. What was the bottom time?

c. Did anything unusual occur during the dive?

(4) How many dives has the patient made in the last 24 hours?

a. Chart profile(s) of any other dive(s).

(5) Were the symptoms ***first noted*** before, during, or after the dive and if after the dive, how long after surfacing?

(6) If ***during*** the dive, did the patient notice the symptom while descending, on the bottom, or during ascent?

(7) Has the symptom either increased or decreased in intensity since ***first noticed?***

(8) Have any additional symptoms developed since the first one?

(9) Has the patient ever had a similar symptom?

(10) Has the patient ever suffered from decompression sickness or gas embolism in the past?

a. Describe this symptom in relation to the prior incident (if applicable).

(11) Does the patient have any concurrent medical conditions which might explain the symptoms?

If available, a review of the diver's Health Record and completed Diving Chart or Diving Log may aid in the evaluation if they are readily available.

Once the history of the dive/injury is completed, a comprehensive neurological examination should be performed. If divers are in Initial Evaluation Category B or C (see paragraph 8-11.1) then there is time to do a complete evaluation. If a divers category becomes more severe during evaluation or if a diver is in Category A ***appropriate recompression treatment should be initiated immediately.*** A more detailed history and examination at treatment depth should be completed after the patient stabilizes.

PART A

H-3 NEUROLOGICAL ASSESSMENT

There are various ways to perform a neurological examination. The quickest information pertinent to the diving injury is obtained by directing the initial examination toward the symptomatic areas of the body. These concentrate on the motor, sensory, and coordination functions. If this examination is normal, the most productive information is obtained by performing the complete examination in the order of:

(1) mental status

(2) coordination

(3) motor

(4) cranial nerves

(5) sensory

(6) deep tendon reflexes

The following procedures are adequate for preliminary examination. Figure H-1 can be used to record the results of the examination.

H-3.1 Mental Status. This is best determined when you first see the patient and is characterised by their alertness, orientation, and thought process. Obtain a good history, including the dive profile, present symptoms and how these symptoms have changed since onset. The patient's response to this questioning and that during the neurological examination will give you a great deal of information about his mental status. It is important to determine if the patient knows the time and place, and can recognise familiar people and understands what is happening. Is the patient's mood appropriate?

Next the examiner may determine if the patient's memory is intact.

Questions such as the following may be helpful:

- What is your Commanding Officer's name?

- What did you have for lunch?

The questions asked should be reasonable and you must know the answer to the questions you ask.

Finally, if a problem does arise in the mental status evaluation, the examiner may choose to assess the patient's cognitive function more fully. Cognitive function is an intellectual process by which one becomes aware of, perceives, or comprehends ideas, and involves all aspects of perception, thinking, reasoning, and remembering. Some suggested methods of assessing this function are:

- The patient should be asked to remember something. An example would be "red ball, green tree, and couch". Inform him that later in the examination you will ask him to repeat this information.

- The patient should be asked to spell a word, such as "world", backwards.

- The patient should be asked to count backwards from 100 by sevens.

- The patient should be asked to recall the information he was asked to remember at the end of the examination.

Most diving casualties have a normal mental status.

Neurological Examination Checklist

(sheet 1 of 2)

(see text of Appendix H for examination procedures and definitions of terms).

Patient's Name: ______________________ Date/Time: ______________

Describe pain/numbness: ______________________________________

____

HISTORY

Type of dive last performed: ____________ Depth: ________ How long: ________

Number of dives in last 24 hours: ______________________________

Was symptom noticed before, during, or after the dive? ______________

If during, was it while descending, on the bottom, or ascending? ______________

Has symptom increased or decreased since it was first noticed? ______________

Have any other symptoms occured since the first one was noticed? ______________

Describe: ____

Has patient ever had a similar symptom before? ____________ When: ____________

Has patient ever had decompression sickness or an air embolism before? ____ When: ______

MENTAL STATUS/STATE OF CONSCIOUSNESS

____

COORDINATION

Walk: ________
Heel-to-Toe: ________
Romberg: ________
Finger-to-Nose: ________
Heel Shin Slide: ________
Rapid Movement: ________

CRANIAL NERVES

Sense of Smell (I) ________
Vision/Visual Fld (II) ________
Eye Movements, Pupils (III, IV, VI) ________
Facial Sensation, Chewing (V) ________
Facial Expression Muscles (VII) ________
Hearing (VIII) ________
Upper Mouth, Throat Sensation (IX) ________
Gag & Voice (X) ________
Shoulder Shrug (XI) ________
Tongue (XII) ________

STRENGTH (Grade 0 to 5)

Upper Body

Deltoids	L ____	R ____
Latissimus	L ____	R ____
Biceps	L ____	R ____
Triceps	L ____	R ____
Forearms	L ____	R ____
Hands	L ____	R ____

Lower Body

Hips

Flexion	L ____	R ____
Extension	L ____	R ____
Abduction	L ____	R ____
Adduction	L ____	R ____

Knees

Flexion	L ____	R ____
Extension	L ____	R ____

Figure H-1. Neurological Examination Checklist (sheet 1 of 2).

Neurological Examination Checklist

(sheet 2 of 2)

REFLEXES

(Grade: Normal, Hypoactive. Hperactive, Absent)

Biceps	L_______	R _______
Triceps	L_______	R _______
Knees	L_______	R _______
Ankles	L_______	R _______

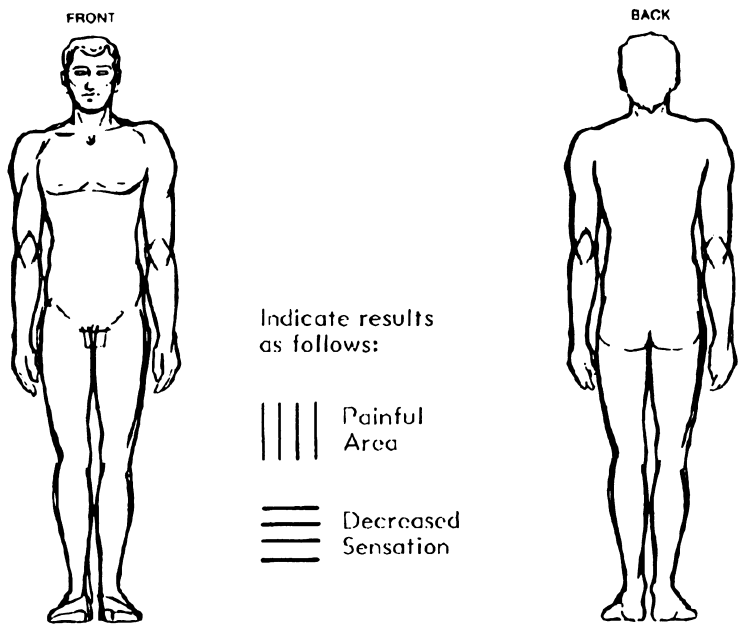
<u>Ankles</u>

Dorsiflexion	L _____	R _____
Plantarflexion	L _____	R _____
<u>Toes</u>	L _____	R _____

Sensory Examination for Skin Sensation

(Use diagram to record location of sensory abnormalities - numbness, tingling, etc.)

LOCATION



COMMENTS

____

____

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Examination Performed By: _______________________

Figure H-1. Neurological Examination Checklist (sheet 2 of 2).

H-3.2 Coordination (Cerebellar/Inner Ear Function). A good indicator of muscle strength and general coordination is to observe how the patient walks. A normal gait indicates that many muscle groups and general brain functions are normal. More thorough examination involves testing that concentrates on the brain and inner ear. In conducting these tests, both sides of the body must be tested and the results must be compared. These tests include:

(1) **Heel-to-Toe Test.** The tandem walk is the standard "drunk driver" test. While looking straight ahead, the patient must walk a straight line, placing the heel of one foot directly in front of the toes of the opposite foot. Signs to look for and consider deficits include:

a. Does the patient limp?

b. Does the patient stagger or fall to one side?

(2) **Romberg Test.** With eyes closed, the patient stands with feet together and arms extended to the front, palms up. Note whether the patient can maintain his balance or if he immediately falls to one side. Some examiners recommend giving the patient a small shove from either side with the fingertips.

(3) **Finger-to-Nose Test.** The patient stands with eyes closed and head back, arms extended to the side. Bending the arm at the elbow, the patient touches his nose with an extended forefinger, alternating arms. An extension of this test is to have the patient, with eyes open, alternately touch his nose with his fingertip and then touch the fingertip of the examiner. The examiner will change the position of his fingertip each time the patient touches his nose. In this version, speed is not important, but accuracy is.

(4) **Heel-Shin Slide Test.** While standing, the patient touches the heel of one foot to the knee of the opposite leg, foot pointing forward. While maintaining this contact, he runs his heel down the shin to the ankle. Each leg should be tested.

(5) **Rapid Alternating Movement Test.** The patient slaps one hand on the palm of the other, alternating palm up and then palm down. Any exercise requiring rapidly changing movement, however, will suffice. Again, both sides should be tested.

H-3.3 Cranial Nerves. The cranial nerves are the 12 pairs of nerves emerging from the cranial cavity through various openings in the skull. Beginning with the most anterior (front) on the brainstem, they are appointed Roman numerals. An isolated cranial nerve lesion is an unusual finding in decompression sickness or gas embolism, but deficits occasionally occur and you should test for abnormalities. The cranial nerves must be quickly assessed as follows:

(I) **Olfactory.** The olfactory nerve, which provides our sense of smell, is usually not tested.

(II) **Optic.** The optic nerve is for vision. It functions in the recognition of light and shade and in the perception of objects. This test should be completed one eye at a time to determine whether the patient can read. The patient should be asked if he has any blurring of vision, loss of vision, spots in the visual field, or peripheral vision loss (tunnel vision). More detailed testing can be done by standing in front of the patient and asking him to cover one eye and look straight at you. In a plane midway between yourself and the casualty slowly bring your fingertip in turn from above, below, to the right and then to the left of the direction of gaze until the patient can see it. Compare this with the earliest that you can see it with the equivalent eye. If a deficit is present, roughly map out the positions of the blind spots by passing the finger tip across the visual field.

(III) **Oculomotor,** (IV) **Trochlear,** (VI) **Abducens.** These three nerves control eye movements. All three nerves can be tested by having the patient's eyes follow the examiner's finger in all four directions (quadrants) an then in towards the tip of the nose (giving a "crossed-eyed" look). The oculomotor nerve can be further tested by shining a light into one eye at a time. In a normal response, the pupils of both eyes will constrict.

(V) The **Trigeminal Nerve** governs sensation of the forehead and face and the clenching of the jaw. It also supplies the muscle of the ear (tensor tympani) necessary for normal hearing. Sensation is tested by lightly stroking the forehead, face, and jaw on each side with a finger or wisp of cotton wool.

(VII) The **Facial Nerve** controls the face muscles. It stimulates the scalp, forehead, eyelids, muscles of facial expression, cheeks and jaw. It is tested by having the patient smile, show his teeth, whistle, wrinkle his forehead and close his eyes tightly. The two sides should perform symmetrically. Symmetry of the nasolabial folds (lines from nose to outside corners of the mouth) should be observed.

(VIII)The **Acoustic Nerve** controls hearing and balance. Test this nerve by whispering to the patient, rubbing your fingers together next to the patient's ears or putting a tuning fork near the patient's ears.

(IX) The **Glossopharyngeal Nerves** transmit sensation from the upper mouth and throat area. It supplies the sensory component of the gag reflex and constriction of the pharyngeal wall when saying "aah". This nerve is tested by touching the back of the patient's throat with a tongue depressor. This should cause a gagging response. This nerve is normally not tested.

(X) The **Vagus Nerve** has many functions, including control of the roof of the mouth and vocal cords. The examiner can test this nerve by having the patient say "aah" while watching for the palate to rise. Note the tone of the voice, hoarseness may also indicate vagus nerve involvement.

(XI) The **Spinal Accessory Nerve** controls the turning of the head from side to side and shoulder shrug against resistance. This nerve is tested by having the patient turn his head from side to side. Resistance is provided by placiing one hand against the side of the patient's head. The examinner should note that an injury to the nerve on one side will will cause an inability to turn the head to the opposite side or weakness/absence of the shoulder shrug on the affected side.

(XII) The **Hypoglossal Nerve** governs the muscle activity of the tongue. An injury to one of the hypoglossal nerves causes the tongue to twist to that side when stuck out of the mouth.

H-3.4 Extremity Strength. It is common for a diver with decompression illness to experience muscle weakness. All muscle groups should be tested and compared with the corresponding group on the other side, as well as with the examiner. Muscle strength is graded (0-5) as follows:

(0) **Paralysis.** No motion possible.

(1) **Profound Weakness.** Flicker or trace of muscle contraction.

(2) **Severe Weakness.** Able to contract muscle but cannot move joint against gravity.

(3) **Moderate Weakness.** Able to overcome the force of gravity but not the resistance of the examiner.

(4) **Mild Weakness.** Able to resist slight force of examiner.

(5) **Normal.** Equal strength bilaterally (both sides), and able to resist examiner.

The testing of extremity strength is divided into two parts: upper and lower body. Each muscle group is compared to the same group in the opposite limb.

There are six muscle groups tested in the upper extremity. They are:

(1) deltoids

(2) latissimus

(3) biceps

(4) triceps

(5) forearm muscles

(6) hand muscles

These muscles are tested with resistance provided by the examiner. The patient should overcome force applied by the examiner which is tailored to the patient's strength. Table H-1 describes the extremity strength tests. The lower extremity strength is assessed by watching the patient walk on his heels for a short distance and then on his toes. The patient should then walk while squatting ("duck walk"). These tests adequately assess lower extremity strength as well as balance and coordination. If a more detailed examination of the lower extremity strength is desired, testing should be accomplished at each joint as in the upper arm. Table H-1 describes the extremity strength tests in more detail.

H-3.5 Sensory Function. Common presentations of decompression sickness in a diver that may indicate spinal cord dysfunction are:

- Pain
- Numbness
- Tingling (pins and needles feeling; also called paresthesia)

An examination of the patient's sensory faculties should be performed. Figure H-2 shows the dermatomal (sensory) areas of skin sensations that correlate with each spinal cord segment. Note that the dermatomal areas of the trunk run in a circular pattern around the trunk. The dermatomal areas in the arms and legs run in a more lengthwise pattern. In a complete examination, each of the spinal segments should be checked for loss of sensation.

Sensations easily recognized by most normal people are sharp/dull discrimination (to perceive as separate), and light touch. It is possible to test pressure, temperature, and vibration in special cases. The likelihood of DCS affecting only one sense, however, is very small.

Table H-1. Extremity Strength Tests.

Test	Procedure
Deltoid Muscles	The patient raises his arm to the side at the shoulder joint. The examiner places a hand on the patient's wrist and exerts a downward force that the patient resists.
Latissimus Group	The patient raises his arm to the side. The examiner places a hand on the underside of the patient's wrist and resists the patient's attempt to lower his arm.
Biceps	The patient bends his arm at the elbow, toward his chest. The examiner then grasps the patient's wrist and exerts a force to straigthen the patient's arm.
Triceps	The patient bends his arm at the elbow, toward his chest. The examiner then places his hand on the patient's forearm and the patient tries to straighten his arm.
Forearm Muscles	The patient makes a fist. The examiner grips the patient's fist and resists while the patient tries to bend his wrist upward and downward.
Hand Muscles	• The patient strongly grips the examiner's extended fingers. • The patient extends his hand with the fingers widespread. The examiner grips two of the extended fingers with two of his own fingers and tries to squeeze the patient's two fingers together, noting the patient's strength of resistance.
Lower Extremity Strength	• The patient walks on his heels for a short distance. The patient then turns around and walks back on his toes. • The patient walks while squatting (duck walk). These tests adequately asesses lower extremity strength as well as balance and coordination. If a more detailed examination of lower extremity strength is desired, testing should be accomplished at each joint as in the upper arm.
In the following tests, the patient sits on a solid surface such as a desk, with feet off the deck.	
Hip Flexion	The examiner places his hand on the patient's thigh to resist as the patient tries to raise his thigh.
Hip Extension	The examiner places his hand on the underside of the patient's thigh to resist as the patient tries to lower his thigh.
Hip Abduction	The patient sits as above, with knees together. The examiner places a hand on the outside of each of the patient's knees to provide resistance. The patient tries to open his kness.
Hip Adduction	The patient sits as above, with knees apart. The examiner places a hand on the inside of each of the patient's knees to provide resistance. The patient tries to bring his kness together.
Knee Extension	The examiner places a hand on the patient's shin to resist as the patient tries to straigthen his leg.
Knee Flexion	The examiner places a hand on the back of the patient's lower leg to resist as the patient tries to pull his lower leg to the rear by flexing his knee.
Ankle Dorsiflexion (ability to flex the foot toward the rear)	The examiner places a hand on top of the patient's foot to resist as the patient tries to raise his foot by flexing it at the ankle.
Ankle Plantarflexion (ability to flex the foot downward)	The examiner places a hand on the bottom of the patient's foot to resist as the patient tries to lower his foot by flexing it at the ankle.
Toes	• The patient stands on tip toes for 15 seconds • The patient flexes his toes with resistance provided by the examiner.

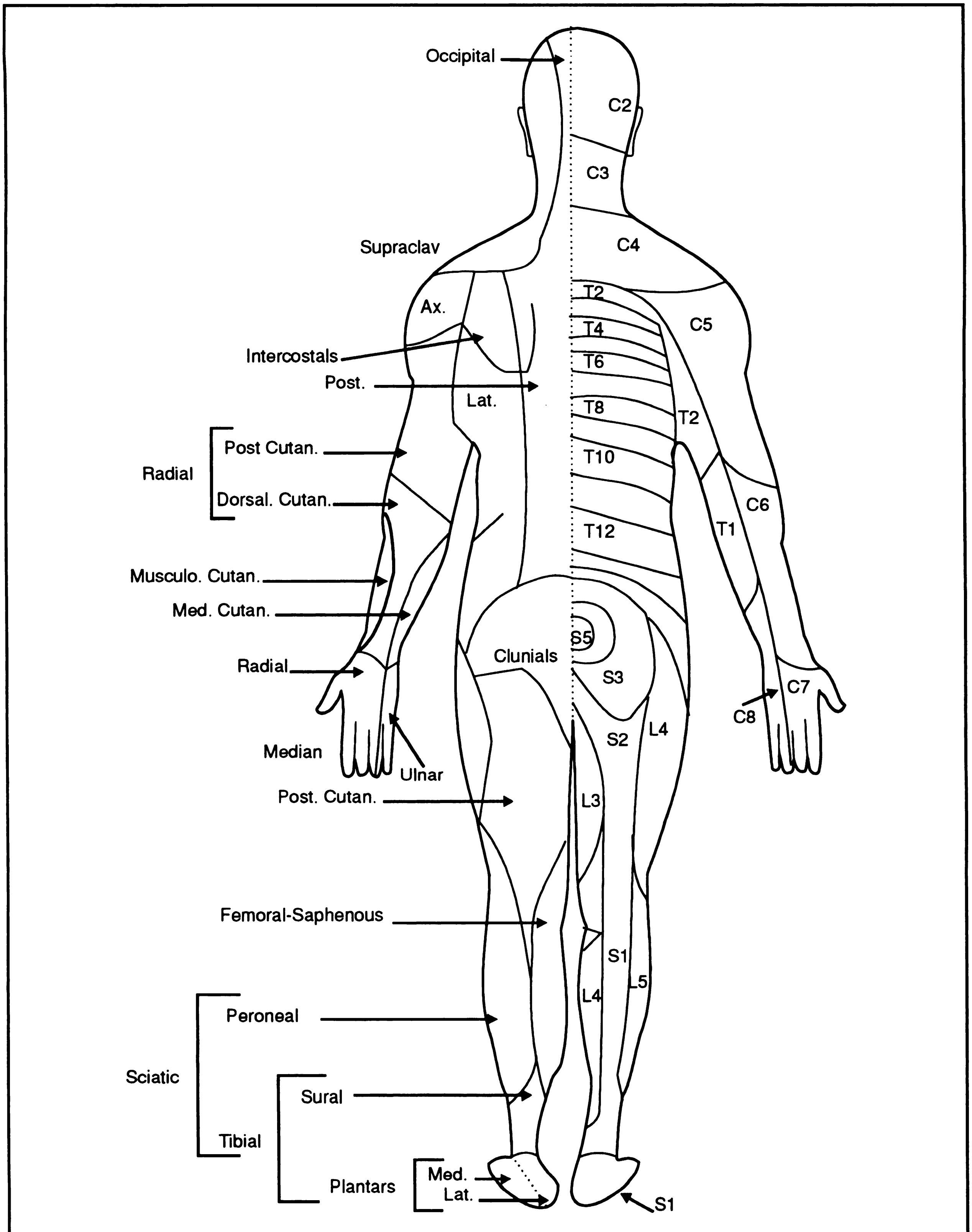


Figure H-2. Dermatomal Areas Correlated to Spinal Cord Segment (sheet 1 of 2).

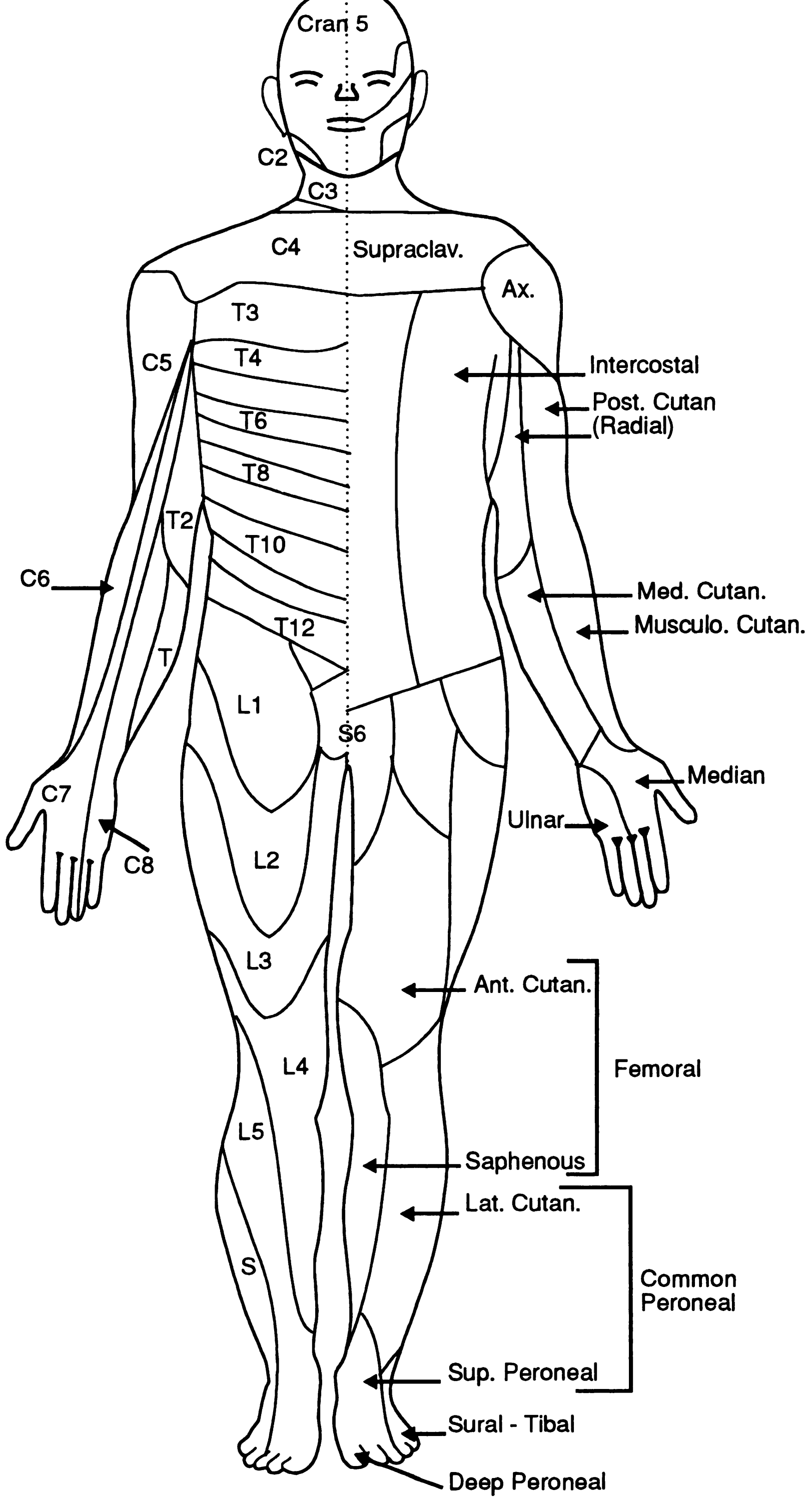


Figure H-2. Dermatomal Areas Correlated to Spinal Cord Segment (sheet 2 of 2).

An ideal instrument for testing changes in sensation is a sharp object such as the Wartenberg pinwheel or a common safety pin. Either of these objects must applied at intervals. Avoid scratching or penetration of the skin. It is ***not*** the intent of this test to cause pain.

The pinwheel or other sharp object should be moved from the top of the shoulder slowly down the front of the torso to the groin area. Another method is to run it down the rear of the torso to just below the buttocks. The patient should be asked if he feels a sharp point, and if he felt it all the time. Each dermatome is tested by going down the trunk on each side of the body. The neck area is tested in similar fashon.

In testing the limbs, a circular pattern of testing is best. Each limb is tested in at least three locations and any difference in sensation on each side of the body is noted. On the arms, the arm is circled at the deltoid, just below the elbow, and at the wrist. In testing the legs, the upper thigh is circled just below the knee and at the ankle.

The hand is tested by running the sharp object across the back and palm of the hand and then across the fingertips.

If an area of abnormality is found, the area is marked for use as a reference point in assessment. Figure H-1, Sheet 2, is an example of the marking method. Some examiners use a marking pen to trace the area of decreased or increased sensation on the body of the patient. During treatment, these areas are rechecked to determine whether the area is improving. An example of improvement is an area of numbness getting smaller.

H-3.6 Deep Tendon Reflexes. The purpose of the deep tendon reflexes is to determine if the patient's response is normal, nonexistent, hypoactive (deficient), or hyperactive (excessive). The patient's response should be compared to responses the examiner has observed before. Notation should be made of whether the responses are equal bilaterally (both sides) and if the upper and lower reflexes are similar. If any difference in the reflexes is noticed, the patient should be asked if there is a prior medical condition or injury that would cause the difference. Isolated differences should not be treated, because it is extremely difficult to get symmetrical responses bilaterally. To get the best response, each tendon is struck with an equal, light force and with sharp, quick taps. Usually, if a deep tendon reflex is abnormal due to decompression sickness, there will be other abnormal signs present. The biceps, triceps, knee, and ankle reflexes should be tested by striking the tendon as described in Table H-2.

Table H-2. Reflexes.

Test	Procedure
Biceps	The examiner holds the patient's elbow with the patient's hand resting on the examiner's forearm. The patient's elbow should be slightly bent and his arm relaxed. The examiner places his thumb on the patient's biceps tendon, located in the bend of the patient's elbow. The examiner taps his thumb with the percussion hammer, feeling for the patient's muscle to contract.
Triceps	The examiner supports the patient's arm at the biceps. The patient's arm hangs with the elbow bent. The examiner taps the back of the patient's arm just above the elbow with the percussion hammer, feeling for the muscle to contract.
Knee	The patient sits on a table or bench with his feet off the deck. The examiner taps the patient's knee just below the kneecap, on the tendon. The examiner looks for the contraction of quadriceps (thigh muscle) and movement of the lower leg.
Ankle	The patient sits as above. The examiner places slight pressure on the patient's toes to stretch the Achille's tendon, feeling for the toes to contract as the Achille's tendon shortens (contracts).

PART B

H-4 INSTRUCTIONS FOR DIVING ACCIDENT CONSULTATION, EXAMINATION AND TREATMENT RECORD (Figure H-3)

This form may be completed when a diver is referred for illness following a dive since it provides a template for a thorough evaluation by medical personnel. Dates should be recorded: month-day-year. Times should be written in the twenty-four hour clock, in local time. Names should be recorded in full, first names first then the family name which should be underlined. This form is designed to serve both as a means of gathering information and as a medicolegal record for the Evaluation. Therefore, it is important that the form is completed as thoroughly as possible. In the case of a telephone consultation pages 1,2,3, and 8 are the minimum required. If the patient is recompressed at your facility all pages should be completed.

Page 1 - Personal Details of Diver and Recent Dives

Details of Initial Contact and Location of Diver The date and time of the initial contact and the contact telephone number for the diver should be recorded. The number should be recorded in full. For example 301-295-1839, any extension number should also be recorded after the main number, for example X4158. Record the location of the diver so that emergency services can locate him/her and so that the closest recompression chamber can be prepared. If at sea, the present position and nearest land should be recorded.

Diver's Personal Details Record the diver's name, gender, date of birth, social security number, service, and main occupation. Note the diver's highest diving qualification by circling the appropriate option printed on the form. If none are appropriate write the correct one down. The name of the diver's employer should be recorded if professional or, if amateur the name of the diving affiliation (e.g. PADI, NAUI, etc.).

Details of Any Dives in the Last 72 hours All dives undertaken in the previous 72 hours should be recorded using one line for each dive. Note the maximum depth reached even if the time at that depth was brief. The duration of the dive is from surface to surface and should be given in minutes as shown. The dive profile describes the depth and the time spent at each depth. The icons are a graphical representation of possible dive profiles. The first box represents a standard square profile dive where a decent is made to a certain depth, the diver stays at that depth for a period of time and then ascends to the surface in a controlled manner making decompression stops as necessary. The second box from the left represents a dive where the ascent is slow. The third box represents a multilevel dive. The fourth is a dive with an emergency or precipitate ascent. The question mark should be used to represent a dive where the profile is unknown. A check should be placed in the box which best represents the dive profile undertaken. This section also provides space to record any decompression stops made and the surface interval between one dive and the next. This interval should be recorded in hours and minutes as shown.

Comments About the Dive(s) This space may be used to record any other relevant information about recent dives.

Purpose of the dive, weather conditions, water temperature, any emergency drills undertaken and any other unusual features should be included. If the exact dive profile is known and is not adequately described above, record it in this box.

Decompression and Location The table or dive computer used should be recorded by circling the appropriate option or by writing an alternative. The way that decompression stops were calculated should be recorded by circling "table" or "computer" as appropriate or if neither of these were used "instinct" should be circled. The location of the dive should be written as it may be different from the location of the diver at the time of presentation.

Page 2 - History of the Principal Manifestations

This page has a number of boxes one for each type of manifestation. The most important piece of information about each manifestations is the date and time that is started. The patient should be specifically questioned about each of the manifestations and negative responses recorded by circling "NONE" in the appropriate box.

Manifestations These are separated into groups: pain; shin; lymphatic; neurological etc. Each symptom should be recorded in the most appropriate box with the date and time of onset. Any additional symptoms, which do not fit in the first five categories, should be recorded in the constitutional section.

Page 3 - History and Past Medical History

Narrative This large space is for the medical attendant to make notes on the history of the presenting complaint as in any other medical history. The symptoms should be described and other diagnostic information recorded. Non-diving illnesses may present during or following diving and such a diagnosis should not be overlooked. Date and time of the most recent alcohol consumption should be recorded if within the last 24 hours.

Evolution This box provides a summary of the main symptoms, the time after the dive that they started and shows whether the symptom is: spontaneously improving (SI); staying the same, static (ST); getting worse, progressive (PR); getting worse again after a period of substantial improvement, relapsing (RE); or if it has disappeared completely, resolved (RS). On the left under manifestation you should write a description of the symptom, SKIN is the example printed on the form. Then the time and date during which the symptomatology is described should be written in, and finally the evolution of the symptom during that time. Thus from the example on the form: we know that from 20:00 on 19 Aug the patient had skin symptoms which were getting worse but by 22:00 the symptoms had peaked and remained the same until midnight, when they began to improve. The symptoms continued to improve until 02:00 when we assume the symptoms are better. If more boxes are needed, for instance if there was a relapse of symptoms, then write "CONTINUED" under "MANIFESTATION" and use the boxes on the new line in the same way as before. This section should be filled in for each manifestation.

Past Medical History Any medical problems, diving related or otherwise, should be recorded in this space. Previous decompression illness, lung disease, cardiovascular disease, neurological disorders, ear nose and throat problems, metabolic disease such as diabetes mellitus and any other medical or surgical conditions should be noted, even if they do not seem relevant. Any drugs taken by the diver should be recorded, with doses. Details of the diver's social habits such as smoking and weekly alcohol intake should also be recorded.

Diagnosis, Referral and Outcome This section is for telephone consultations only. Any diagnosis or referral advice should be recorded.

Pages 4 and 5 - Clinical Examination

It will be assumed that the examination is conducted on the surface, prior to recompression unless otherwise stated. Any examination findings at depth should be recorded in the "Additional Examination Notes" section.

Examining Doctor The name of the doctor conduction the clinical examination should be recorded along with his position for example general medical officer, Emergency room attending, diving medical officer, etc.

General Examination In this box the results of a general examination should be recorded next to the appropriate system headings on the left. Abnormalities present should be recorded in detail next to the appropriate heading. If a field is left blank this will be taken to mean that the test was not done, if the test was done and was normal this should be recorded by writing "NORMAL" or "N". Of particular importance is examination of tympanic membranes, the neck for subcutaneous emphysema, skin for rash or swelling (lymphoedema) and lymph nodes for tenderness and swelling.

Neurological Examination

Higher Function The assessment of higher cerebral function should be recorded here. Next to "Mental status" there are some examples of information required, but any abnormality of higher function must be recorded. The patient's personality can be affected by decompression illness and asking a friend of the patient whether the patient's behavior is normal is desirable. If severely compromised the level of consciousness may be recorded using the Glasgow Coma Scale by adding together the following scores to give the Glasgow Coma score in the range 3 to 15.

Eyes Open Spontaneously-4, to verbal command-3, to pain-2 and if the eyes remain closed despite these stimuli-1.

Best Motor Response Obeys verbal commands-6, on giving a painful stimulus: localises pain-5, flexion withdrawal-4, abnormal flexion (like decorticate rigidity)-3, extension response-2 and no response at all-1.

Best Verbal Response Orientated and converses-5, disorientated but converses-4, inappropriate words-3, incomprehensible sounds-2 and no verbal response at all-1.

Coordination In this, section abnormalities of coordination should be recorded. The tests indicated should be carried out and the results recorded in the space provided. If normal, record this and if not, the abnormality should be described avoiding ambiguous terms.

Reflexes The reflexes should be tested and the results recorded here in the following way: if normal write "N", if brisk write "B", if sluggish write "S" and if absent despite reinforcement, write "A". The status of the reflex should be written in this way in the space provided to the right of the "R" or "L" in the box. For the plantar reflex write "up" or "down" or as an alternative draw an arrow pointing to the top of the page for upgoing plantar reflex or at the bottom of the page for downgoing reflex.

Cranial Nerves This box shows the cranial nerves, which may be examined. If normal this should be recorded next to the nerve number which is written in Roman numerals. If normal is written it will be taken to mean normal both sides. Any abnormality should be described taking care to record which side it is on.

Power On the right side of this box is a key which shows first how to record movements for example flexion is written "FL". Below is a power scale where the muscle power is described by a number between 0 and 5. This scale was devised for use in sufferers of paralytic poliomyelitis but is now in widespread use. Each muscle group should be tested and its movement recorded. If movement at a joint is normal write "NORMAL" under movement and if the power of all muscle groups around the joint is normal writing "5". If there are abnormalities they must be individually recorded.

Sensation This section has a diagrammatical man drawn in it, but the same diagram should be used for women. The location of any abnormality of sensation should be indicated by shading areas on the diagram. If different modalities of sensation are affected in different distributions a variety of shading styles may be used to represent different modalities. For example temperature perception may be represented by crown-hatching and two-point discrimination deficits represented by stippling. It is important to test perineal (around the rectum) sensation and sphincter tone.

Additional Examination Notes Any information gathered during the examination which has not been recorded elsewhere or the results of examination at depth should be recorded in this section.

Diagnosis The diagnosis reached, based on history and examination should be recorded in this box. If a decompression illness is diagnosed, it should be written down using the classification with which the doctor is familiar.

Pages 6 and 7 - Treatment

Treatment Prior to Recompression Fluid therapy is important in any diving illness. It should be recorded by circling the route of administration, writing in the volume given and indicating the type of fluid given. Breathing high concentrations of oxygen (ideally 100%) is important first aid. The duration, concentration, flow rate and mode of delivery should be recorded. Concentrations of oxygen approaching 100% will only be achieved by a reservoir system or by demand valve attached to a supply of pure oxygen. Any drugs administered, dose and route of administration should be recorded. If the diver is recompressed the mod of transport, date and time of arrival and the name and location of the chamber should be recorded.

Recompression The date and time the treatment table commenced should be recorded in the appropriate column on the left. Each line represents one treatment table, as some patients require more than one treatment extra lines are available. The table number should be circled if an USN 5 or 6, or the name or number written in if it is not. Table 6 may be extended at either 60ft or 30ft and if this is necessary it should be recorded by circling "x1" or "x2" as shown next to the relevant depth for one or two extensions respectively. If the table is not extended "x0" should be circled for both depths. In cases where the table used is other than a standard USN table the maximum depth and the total duration of the table should be recorded in the spaces provided. In the column on the right are options to describe the state of the patient at the end of the treatment. The most appropriate should be circled. Other information about the treatment can be recorded in the large space for "treatment narrative".

Fluid Balance Chart This should be completed in the conventional way for fluid balance during recompression treatment. Urinary catheterization may be necessary, particularly in cases of spinal cord decompression illness where bladder problems may occur. Most injured divers will be dehydrated and should be given appropriate fluids either orally or intravenously depending on the clinical condition.

Medication All drugs given during treatment at the chamber should be recorded in this section, using generic names.

Treatment Narrative This large space is for the doctor to record important clinical information not recorded elsewhere. The point at which the diver gets relief of symptoms and signs, problems during treatment and any other information of relevance may be recorded.

Page 8 - Follow up

Investigations any results of special investigations done during or after treatment should be recorded in this space. These may vary according to the specific case but may include chest X-ray, biochemistry for example for blood sugar and any other test which may be appropriate, give evidence for or against non-diving related diseases or otherwise be relevant to treatment or determining fitness to dive in the future.

Patient Discharge Location The place to which the patient is sent following treatment should be recorded. If a hospital, the name should be written as well as circling "hospital".

Diver's and Personal Practitioner's Address The diver's address should be recorded as should his Doctor's name and address. A record of correspondence with the Doctor should be indicated by circling the "yes" option next to "letter sent to Doctor" and writing the date any letter was sent.

Diagnosis The diagnosis reached by the attending doctor should be written.

Review It is desirable to review patients about a month after the incident. At this consultation the date and any residual symptoms or signs should be recorded. Any further treatment or specialist referral should be recorded.

The attending doctor should sign and date the form.

11/92

Accident No.

Diving Accident Consultation, Examination, and Treatment

DATE OF CALL		TIME		PHONE	

NAME OF CALLER

LOCATION OF PATIENT

PATIENT NAME

SEX	M F	DATE OF BIRTH		SSN	
SERVICE/ CIVILIAN	USN / USMC / USA / USAF / USCG / CIVILIAN	RATE/RANK OCCUPATION	USN / USMC / USA / USAF / USCG / CIVILIAN		

DIVE STATUS (Qualification)	Professional	SCUBA / 2ND / 1ST / MASTER / SATURATION / EOD / SPEC WAR / Part I / Part II / Part III / Part IV / Other
	Amateur	Novice / Sport Diver / Dive Leader / Advanced Diver / 1st Class Diver / Instructor (BSAC)

Employer/Club

DETAILS OF DIVES WITHIN LAST 72 HOURS

Date (M/D/Y)	Start Dive (Time	Max. Depth (ft)	Dive Duration (min)	Dive Profile (Mark)					Decompression Stops Depth (ft), Time(min)										Surface Interval
								?	D	T	D	T	D	T	D	T	D	T	

Comments about the dive(s):

TABLE USED	USN / PADI Rec Dive Planner / NAUI / PADI USN / NONE / OTHER (NAME)	COMPUTER USED	Edge / Skinny Dipper / Suunto / Datamaster / None / OTHER(NAME)
DECOMPRESSION BY	Table Computer Instinct	LOCATION OF DIVE(S)	

1

Figure H-3. Neurological Examination Checklis (sheet 1 of 9).

HISTORY

HISTORY - PRINCIPAL MANIFESTATIONS.

Circle the appropriate manifestation(s) and note the TIME (24hr clock) and where necessary, the DATE of ONSET.
Where there is no evidence of a manifestation, circle NONE .

PAIN NONE — Time and Date of ONSET

GIRDLE

JOINT PAIN

Shoulder	R	L
Elbow	R	L
Wrist	R	L
Hip	R	L
Knee	R	L
Ankle	R	L

Other
(specify)

SKIN NONE — Time and Date of ONSET

Itching

Redness

Marbling

Other
(specify

LYMPHATIC NONE — Time and Date of ONSET

Lymph node — enlarged/painful

Swelling

NEUROLOGICAL NONE — Time and Date of ONSET

Level of Consciousness

Higher Function — Aberration of thought / Loss of memory / Personality change / Dysphasia / Seizure

Special Senses — Hearing loss / Vertigo / Tinnitus / Nystagmus / Visual impairment

Strength

Sensation — Numbness / Paraesthesiae

Sphincter Function — Bladder / Bowel

PULMONARY NONE — Time and Date of ONSET

Cough / SOB / Chest Pain / Hemoptysis / Cyanosis / Subcutaneous Emphysema / Voice Change / Pneumothorax

CONSTITUTIONAL NONE — Time and Date of ONSET

Anorexia / Excessive Fatigue / Malaise / Headache / Vomiting

2

Figure H-3. Neurological Examination Checklis (sheet 2 of 9).

HISTORY

NARRATIVE

EVOLUTION: From the history above, summarize the significant changes in each principal manifestation PRIOR TO RECOMPRESSION. These changes may be expressed as: unchanged in intensity (STATIC); getting worse (PROGRESSIVE); SPONTANEOUSLY IMPROVING, getting worse again after a period of substantial improvement (RELAPSING); or it may have disappeared completely (RESOLVED). If no time interval is specified, it will be assumed that the evolution term used applies to the entire period prior to recompression.

Note the TIME INTERVAL (including dates where necessary) of any change.

MANIFESTATION	Time Interval	Evolution	Time Interval	Evolution	Time Interval	Evolution
Example: SKIN	*19 Aug 2000-2200*	*PR*	*19 Aug 2200-2359*	*ST*	*20 Aug 0001-0200*	*SI*

RELEVANT PAST MEDICAL HISTORY

State details of any recent medical condition

Medication:

For Telephone Consultations Only

Diagnosis:

Referred to: Chamber (please specify) / Patient's Physician / Hospital / Other

Outcome of Consult:

3

Figure H-3. Neurological Examination Checklis (sheet 3 of 9).

EXAMINATION

Patient examined by

GENERAL SYSTEMS EXAMINATIION

ENT

Cardiovascular System

Pulmonary System

GI system

Skin

Lymphatic System

NEUROLOGICAL ASSESSMENT

Mental Status Orientation in time / space / memory / mood / cognitive function

Level of consciousness

COORDINATION

Gait	Finger/nose
Heel-to-toe Walk	Rapid movement
Heel shin slide	Rhomberg

REFLEXES (Normal, Brisk, Sluggish, Absent)

Biceps	R	L	Knee	R	L
Triceps	R	L	Ankle	R	L
Supinator	R	L	Plantar	R	L
Abdominal	R	L	Cremaster	R	L

CRANIAL NERVES

Vision Visual Fields	II	Mouth/Throat Sensation	IX
Pupils/Eye Movements Nystagmus	III,IV,VI	Gag, Palate Movement	X
Facial Sensation Corneal Reflex	V	Shoulder/Neck	XI
Facial Expression	VII	Tongue	XII
Hearing	VIII		

POWER

JOINT	R/L	MOVEMENTS (see key)	POWER (see scale) Record Tone as appropriate
Shoulder			
Elbow			
Wrist			
Fingers			
Hip			
Knee			
Ankle			
Toes			

MOVEMENT KEY

FLexion
EXtension
ABduction
ADduction
ROtation

POWER SCALE

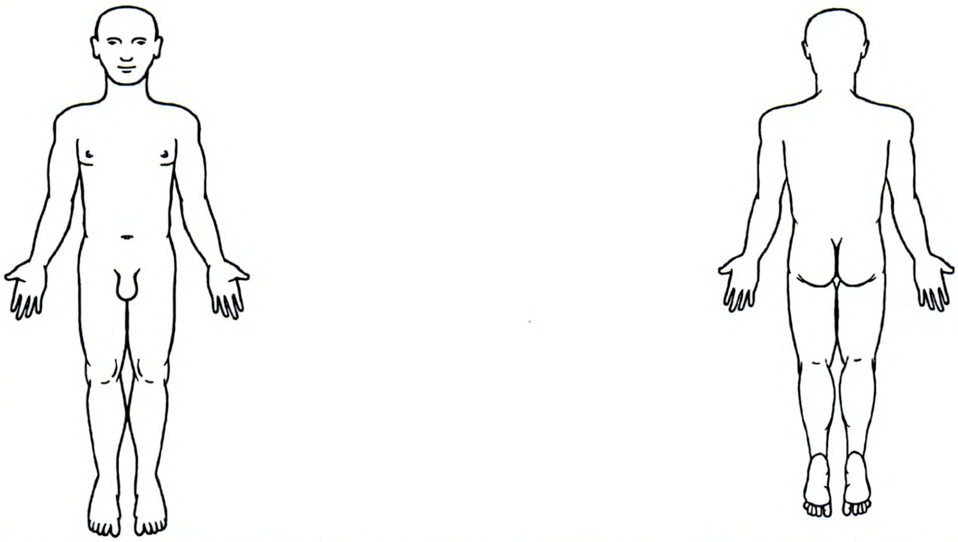
0 No movement possible
1 A flicker of movement
2 Muscle contracts but can't overcome gravity
3 Can overcome gravity but not the examiner
4 Slight weakness
5 Normal

4

Figure H-3. Neurological Examination Checklis (sheet 4 of 9).

EXAMINATION

Use the diagram to record location of sensory abnormalities - light touch, pin prick, temperature sensation, vibration, proprioception, etc.
(Note whether objective and/or subjective where appropriate)



ADDITIONAL EXAMINATION NOTES

DIAGNOSIS(ES)

5

Figure H-3. Neurological Examination Checklis (sheet 5 of 9).

TREATMENT

TREATMENT PRIOR TO RECOMPRESSION

Fluids: None / IV / Oral — Volume: ____ ml — Type: ____

Oxygen: None — Duration: ____ min — Inspired PO_2: ____ % — Flow: ____ l/min

Means of delivery: Oronasal mask / Nasal cannula / Demand system / ET tube / Other

Drugs: Name, Dose, Route: ____

Transport to Chamber: Air / Road / Sea — Date/Time of arrival at Chamber: ____

Chamber Used: ____

RECOMPRESSION (Record ALL Recompression Treatments for this incident)

Date	Start Time	Table Description / Profile	Outcome
		USN 6 / USN 5 / Other (Specify) Extensions: 60ft x0 x1 x2 30ft x0 x1 x2 Max Depth Duration	Recovered / Improved / Unchanged / Worse / Dead
		USN 6 / USN 5 / Other (Specify) Extensions: 60ft x0 x1 x2 30ft x0 x1 x2 Max Depth Duration	Recovered / Improved / Unchanged / Worse / Dead
		USN 6 / USN 5 / Other (Specify) Extensions: 60ft x0 x1 x2 30ft x0 x1 x2 Max Depth Duration	Recovered / Improved / Unchanged / Worse / Dead
			Recovered / Improved / Unchanged / Worse / Dead
			Recovered / Improved / Unchanged / Worse / Dead
			Recovered / Improved / Unchanged / Worse / Dead
			Recovered / Improved / Unchanged / Worse / Dead

FLUID BALANCE

Fluid Given	Route	Date/ Time	Volume (ml)	Running Total	Fluid Out	Date/ Time	Volume (ml)	Running Total
TOTAL IN					TOTAL OUT			

MEDICATION

Drug Name	Dose	Route	Date / Time	Signed

6

Figure H-3. Neurological Examination Checklis (sheet 6 of 9).

TREATMENT

TREATMENT NARRATIVE

Include time to relief of symptoms/signs and whether complete or partial; any problems during treatment, including details of any transfer to alternative tables; the patients condition at the end of initial treatment and progress during any retreatment.

7

Figure H-3. Neurological Examination Checklis (sheet 7 of 9).

SUMMARY

INVESTIGATIONS

This space should be used for reporting the results of any investigations.

PATIENT DISCHARGED TO:	HOME / HOSPITAL / OTHER
PATIENT'S HOME ADDRESS	ZIP CODE PHONE
PATIENT'S PERSONAL PHYSICAN	NAME Unknown ADDRESS ZIP CODE PHONE LETTER SENT: NO YES DATE SENT:
FINAL DIAGNOSIS(ES)	

NAME OF DOCTOR	SIGNATURE	DATE

REVIEW

This space should be used for reporting the patient's condition at subsequent review.

8

Figure H-3. Neurological Examination Checklis (sheet 8 of 9).

CONTINUATION SHEET

Page No:

Use this page for additional notes for History narrative, Additional Examination Notes, Treatment Narrative, or any other areas where insufficient space is available to record all the necessary details.

Name of Patient		Date of Birth		Age	

Name of Doctor	Signature	Date
	MEDICAL-IN- CONFIDENCE	

Figure H-3. Neurological Examination Checklis (sheet 9 of 9).

APPENDIX I

DIVER'S AIR SAMPLING

I-1 INTRODUCTION

Diver's breathing air must be free of carbon monoxide (CO), carbon dioxide (CO_2), oil vapor, and other impurities (see Appendix L). Many gaseous and particulate contaminants adversely affect the human body when the partial pressure of the gases is increased. To monitor diver breathing air purity, the Naval Sea Systems Command (NAVSEASYSCOM) has established an air sampling program which is described in NAVSEA Note 9597, Diver's Breathing Air Sampling Program for Compressed Air Sources, 27 May 1977. The NAVSEASYSCOM air sampling program is administered by the Coastal Systems Station, Panama City Beach, FL 32407-5001 (COASTSYSTA).

I-2 DEFINITIONS

- **Contractor -** Qualified analytical laboratory that supplies the sampling equipment and analytical services.
- **Managing Activity -** Naval activity administering the program (COASTSYSTA).
- **Sponsor -** Naval Sea Systems Command.
- **User -** Activity, group, ship, command, etc., with a diving capability.
- **Sampling Kit -** Kit of sampling equipment tailored to the user's needs, packaged and sent to the user by the contractor.
- **Sample Set -** Complete set of specimens (samples) obtained from an air supply source. The set consists of the following:

  (1) Particulate sample (filter pad).

  (2) Diving air sample.

I-3 SAMPLING PROCEDURES

I-3.1 Administration.

- **Sampling Period -** Each diver breathing air source in service must be checked for purity at intervals not to exceed six months.
- **Action Upon Detection of Substandard Samples -** The user will be contacted by phone and message as quickly as possible by COASTSYSTA if the sample fails to meet established purity standards. The user will discontinue use of the air source until cause of contamination is corrected. The laboratory will aid in determining the cause of the bad sample and advise if resampling is necessary.
- **Sampling Schedule -** COASTSYSTA will coordinate scheduling for all commands requesting divers air samples. The user shall notify the COASTSYSTA representative via telefax or message approximately four to six weeks prior to sample expiration date. The user must provide the sample expiration date, the number and type of samples required, a complete mailing address, user point of contact and correct phone number. Only when the information requested above is provided will an air sample kit be shipped. Commands requesting air samples should schedule **all** compressors and associated samples to be taken at the same time. Each

command will receive two sample kits per year (one kit every six months).

- Unscheduled Sampling - Air sampling equipment needed between the scheduled sampling periods may be obtained by notifying COASTSYSTA, Attn: Code N2530 Phone A/V 436-4482 Comm. (904) 234-4482. **The user must not communicate directly with the contractor.** Unscheduled samples will be processed at the commands expense. Because of the sporadic nature of air sampling schedule requirements of Explosive Ordnance Disposal (EOD) mobile detachments and submarines, these two activities are not scheduled on a six-month basis. Orders for air sampling kits must be placed with COASTSYSTA each time these users desire sampling. EOD mobile detachments may apply directly to COASTSYSTA, or order sampling kits through the EOD Mobile Unit to which they are assigned. Submarines may apply directly to COASTSYSTA, or order sampling kits through the Submarine Squadron or Group (in accordance with group policy) to which they are assigned.

- **Shipping -** A self-addressed prepaid postage tag or return commercial carrier tag is included with the instructions. **Sampling kits are sent by commercial air carrier within the United States and Certified Priority Mail overseas via the Fleet Post Offices (FPO).**

- **Late Fees -** Sampling must be accomplished in a timely manner. The contractor charges a fee for each day the kit is late in return. Late days begin to accrue when a kit shipped within the United States is not returned within 20 days of the contractor shipping date, or within 40 days of the contractor shipping date if shipped outside the United States. Users currently in possession of an overdue kit will not receive any additional sampling kits and will be responsible for accrued late charges.

- **Administrative Instructions -** Each user is responsible for conducting air sampling. Sampling and return mailing should be completed within **three** working days after receipt of the kits. A self-addressed prepaid postage tag or return commercial carrier tag is included with the instructions. Compressed air and particulate samples are taken from diving stations, SCUBA charging stations, air banks, and/or compressors. An ambient air sample is taken at the compressor intake. Data taken during the sampling procedure is recorded on the data sheet supplied with the kit.

I-3.2 Air Sampling Instructions. Detailed instructions for using the air sampling equipment are included in the kit.

1-3.2.1 System Sampling Requirements. Divers Life Support Systems (DLSS) shall be sampled semi-annually. Samples should be taken at the compressor supply points only. Additional samples are not required. Systems that do not have a compressor within the scope of certification should ensure HP banks are charged by certified compressors with current air samples.

I-3.2.2 Sampling of High-Pressure Charging Systems. Separate samples should be taken from each compressor supplying the system. Samples from the compressors should be taken as close to the compressor as possible, but downstream of the **last** compressor-mounted air treatment device (moisture separator, filter, etc.) and upstream of the system moisture separator and filter. Some systems do not have fittings that allow samples to be taken from the system at a location other than the SCUBA charging connection. In this case the storage flasks should be isolated from the system, the system purged with air from the compressor to be sampled, and the sample taken at the SCUBA charging connection. Repeat the procedure for each of the compressors connected to the system.

I-3.2.3 Sampling of Low-Pressure Systems. Separate air samples from a low-pressure (LP) breathing air system should be taken from each LP compressor connected to the system. Samples should be taken from each LP compressor as close to the compressor as possible but **after the last** compressor-installed air treatment device (moisture separator, filters, etc.) and upstream of the moisture separator and filter. Some systems do not have fittings that allow samples to be taken at connections other than the dive manifold. In this case any high-pressure (HP) sources should be isolated from the LP system, the system purged with air from the LP compressor to be sampled, and the sample obtained from the diver's manifold. Repeat the procedure for each compressor connected to the system. A surface-supplied diving air system is classified as a low-pressure high-capacity air source.

APPENDIX J

ICE/COLD WATER DIVING OPERATIONS

J-1 INTRODUCTION

Polar regions and other cold weather environments are uniquely hostile to divers, topside support personnel, and equipment. Diving where ice cover is present can be extremely hazardous and requires special equipment as well as appropriate operating and support procedures. Awareness of environmental conditions, personnel and equipment selection, and adequate logistical support are vital to mission success and dive team safety.

J-2 THE ENVIRONMENT

J-2.1 Extreme Cold Conditions. For information on extreme cold weather conditions and the polar environment, refer to *A Guide to Extreme Cold Weather Operations* (Naval Safety Center, July 1986), *Polar Operations Manual* S0300-85-MAN-010 (Naval Coastal Systems Center (NCSC), and *Guide to Polar Diving* (Office of Naval Research, June 1976), to obtain contact NCSC, Code 5110, Autovon 436-5414.

J-2.2 Navigation. Conditions in cold and ice-covered water affect diver underwater navigation:

- The proximity of the magnetic pole in polar regions makes the magnetic compass useless.
- When used in cold water, the life of batteries in homing beacons, strobes and communication equipment is shortened.
- Surface light is so diffused by ice cover that it is nearly impossible to determine its source.
- Direct ascent to the surface is impossible when under the ice, and determining return direction is often hindered.
- In shallow ice-covered waters, detours are often required to circumvent keels or pressure ridges beneath the ice.
- With an ice cover, there are no waves, therefore, no ripple patterns on the bottom to use for general orientation.

J-3 OPERATIONS PLANNING

Normal diving procedures generally apply to diving in extremely cold environments. However, there are a number of significant equipment and procedural differences which enhance the diver's safety.

J-3.1 Planning Guidelines. The following planning considerations are relevant to ice-covered and cold water diving operations:

- The task and requirement for ice diving should be reviewed to ascertain that it is operationally essential.
- Environmental conditions, e.g., ice thickness, water depth, temperature, wind velocity, current, visibility, and light conditions should be determined. Ideally, a reconnaissance of the proposed dive site is performed by the Diving Supervisor or a person with ice-covered/cold water diving experience.
- The type of dive equipment chosen must be suited for the operation.
- Logistical planning must include trans-

portation, ancillary equipment, provisioning, fuel, tools, clothing and bedding, medical evacuation procedures, communications, etc.

J-3.2 SCUBA Considerations. SCUBA equipment has advantages and disadvantages that should be considered when planning a cold water dive. The advantages of SCUBA equipment are its portability, quick deployment, and minimal surface support requirements. The disadvantages are depth limitations, limited communications, severely limited ability to employ decompression diving techniques, and duration limitations of CO_2 removal systems in closed-circuit UBA.

J-3.2.1 SCUBA Regulators. The single-hose regulator is susceptible to freezing. The first stage of the single-hose regulator may freeze in the free-flow position after 20 to 30 minutes of exposure in cold water (below 37°F).

The single-hose regulator should be kept in a warm place before diving. It is important that the diver test the regulator in a warm place, then refrain from breathing it until submerging. When returning to the surface, the regulator should remain submerged and the diver should refrain from breathing from the regulator until resubmerging. The diver's time on the surface should be kept to a minimum. Once under the water, chances of a freeze-up are reduced. However, if a regulator is allowed to free-flow at depth for as little as five seconds, freeze-up may occur. The diver should therefore avoid purging the second stage of the regulator when diving in cold water. If water needs to be purged from the mouthpiece, the diver should do so by exhaling into it. Single-hose regulators should be equipped with an antifreeze cap (a special first-stage cap that can be filled with liquid silicone available from the manufacturer). Correct maintenance and application of an approved lubricant to the appropriate points is also essential. Extra precautions must also be taken to make sure that SCUBA cylinders are completely dry inside, that moisture-free air is used, and that the regulator is thoroughly dried prior to use. Where water temperature is at or below 37°F, a redundant SCUBA system (twin SCUBA bottles, each having a "K" valve and an approved cold water regulator) or twin SCUBA bottles with one common manifold and an approved cold water regulator (with octopus) may be used. When selecting the redundant SCUBA system, maximum depth and bottom time is greatly reduced because the extra SCUBA shall be used for emergencies only. Table J-1 presents cold water performance of various SCUBA regulators.

J-3.2.2 Life Preserver. The use of life preservers is prohibited only when diving under ice. The accidental inflation of a life preserver

Table J-1. Single Hose SCUBA Regulator Performance in Cold Water.

Regulator Name	Cold Water Rating	Human Factors Rating
AGA DIVATOR MKII breathing valve with AGA mouthpiece/U.S. Divers Royal SL first stage	Superior	Superior
Poseidon Cyklon 500	Superior	Moderate
Poseidon ODIN	Superior	Moderate
Poseidon THOR	Superior	Moderate
U.S. Divers Conshelf XIV	Untested	Superior

will force the diver upward, and may cause a collision with the undersurface of the ice. Should the diver be caught behind a pressure ridge or other subsurface ice structure, recovery may be difficult even with tending lines. Also, the exhaust and inlet valves of the variable volume dry suit will be covered if a life preserver is worn. In the event of a dry suit blow-up, the inability to reach the exhaust dump valve could cause rapid ascent and collision with the surface ice.

J-3.2.3 Face Mask. The diver's mask may show an increased tendency to fog in cold water. An antifog solution should be used to prevent this from occurring. Saliva will not prevent this fogging.

J-3.2.4 SCUBA Equipment. The minimum equipment required by every Navy SCUBA diver for under ice operations consists of:

- Wet suit/variable volume dry suit
- Open-circuit SCUBA with cold water modification or closed-circuit UBA
- Face mask
- Weight belt and weights (as required)
- Knife and scabbard
- Swim fins
- Wrist watch
- Depth gauge
- Submersible SCUBA bottle pressure gauge
- Harness (i.e., Integrated Divers Vest (IDV), MK 12 jocking harness, etc.)
- Lifelines

A variety of special equipment (underwater cameras, lift bags, etc.) is available to divers (see NAVSEAINST 10560.2 series for specific identification of authorized equipment). However, the effect of extreme cold on the operation of special equipment must be ascertained prior to use.

J-3.3 Surface-Supplied Diving System (SSDS) Considerations. The use of SSDS in ice-covered or cold water requires detailed operations planning and extensive logistical support. This includes thermal protection for an elaborate dive station and recompression chamber, and hot water heating equipment. In addition, dive equipment may require cold climate modification. Because of logistical considerations, SCUBA is used in most ice diving situations; however, SSDS may be required because of prolonged bottom times, depth requirements, and complex communications between topside and diver. When diving in cold water that is not ice covered, logistic and equipment support requirements are reduced; however, very cold water poses many of the same dangers to the surface-supplied diver as ice diving. The advantages and disadvantages of using SSDS are listed below.

Advantages:

- Configuration supports bottom-oriented work.
- Hot water suit and variable volume dry suit offer diver maximum thermal and environmental protection.

- Communications cable offers audio communications.

- Gas supply allows maximum duration to the maximum depth limits of diving.

Disadvantages:

- Manifold/panel may freeze-up.

- Low-pressure compressors do not efficiently remove moisture from the air which may freeze and clog filters or fracture equipment. This is more probable when the water is very cold and the air is warm. Banks of high-pressure cylinders may have to be used.

- Build-up of air or gas under the ice cover could weaken and fracture thin ice endangering tenders, other topside personnel, and equipment.

- Movement of ice could foul or drag diver's umbilical.

- Battery life of electronic gear is severely reduced.

- Carbon dioxide removal recirculator components may have to be heated.

- Decompression under extreme cold conditions may be dangerous due to water temperature, ice movement, etc.

Even though it is clear that SSDS has several disadvantages, there are contingencies such as complex rescue and salvage missions which would dictate its use.

J-3.3.1 Effect of Ice Conditions on SSDS. Ice conditions can prevent or severely affect surface-supplied diving. In general, the ice field must be stationary and thick enough to support the dive station and support equipment. If the dive must be accomplished through an ice floe, the floe must be firmly attached to land or a stable ice field. Severe ice conditions seriously restrict or prohibit surface-supplied diving through the ice (i.e., moving, unstable ice or pack ice and bergs, and deep or jagged pressure ridges could obstruct or trap the diver). In cases where a diver is deployed from a boat in a fixed mooring, the boat, divers, and divers' umbilicals must not be threatened by moving ice floes.

J-3.4 Suit Selection. Custom wet suits designed for cold water diving, variable volume dry suits, and hot water suits have all been used effectively for diving in extremely cold water. Each has advantages and disadvantages which must be considered when planning a particular dive mission. All suits must be inspected before use to ensure they are in good condition with no seam separations or fabric cuts.

J-3.4.1 Wet Suits. Custom wet suits have the advantages of wide availability, simplicity, and less danger of catastrophic failure than dry suits. Although the wet suit is not the equipment of choice, if used the following should be considered.

- The wet suit should be maintained in the best possible condition to reduce water flushing in and out of the suit.

- The use of heavy insulating socks under the boots in a wet suit will help keep feet warm.

CAUTION

In very cold water, the wet suit is only a marginally effective thermal protective measure and its use exposes the diver to hypothermia and restricts available bottom time. The use of alternative thermal protective equipment should be considered in these circumstances.

J-3.4.2 Variable Volume Dry Suits. These suits provide superior thermal protection to the surface-supplied or SCUBA diver in the water and on the surface. They are constructed so the entry zipper or seal, and all wrist and neck seals are waterproof, keeping the interior dry. They can be inflated orally or from a low-pressure air source via an inlet valve. Air can be exhausted from the suit via a second valve, allowing excellent buoyancy control. The level of thermal protection can be varied through careful selection of the type and thickness of long underwear. However, too much underwear is bulky, and can cause overheating, sweating, and subsquent chilling of the standby diver. Dry suit disadvantages are: increased swimmer fatigue due to suit bulk, possible malfunction of inlet and exhaust valves, and the need for additional weights for neutral buoyancy. Furthermore, if the diver is horizontal or deployed with the head below the rest of the body, air can migrate into the suit lower extremities, causing overinflation and loss of fins and buoyancy control. A parting seam or zipper could result in a dramatic loss of buoyancy control and thermal shock. Nevertheless, because of its superior thermal protection, the dry suit is an essential component of extremely cold water diving.

CAUTION

Prior to the use of variable volume dry suits and hot water suits in cold and ice-covered waters, divers must be trained in their use and be thoroughly familiar with the operation of these suits.

J-3.4.3 Extreme Exposure Suits/Hot Water Suits. Hot water suits provide excellent thermal protection. If their use can be supported logistically, they are an excellent choice whenever bottom times are lengthy. They are impractical for use by standby divers exposed on the surface.

A failure of the hot water system can be catastrophic for a diver in very cold water since the hot water is a life support system under such conditions. Hot water temperature must be carefully monitored to ensure that the water is delivered at the proper temperature. When using the hot water suit, wet suit liners must be worn. The hose on the surface must be monitored to ensure it does not melt into the ice. When not in use, the heater and hoses must be thoroughly drained and dried to prevent freezing and rupture.

J-3.5 Clothing. Proper planning must include the protection of tenders and topside support personnel from the environment. However, bulky clothing and heavy mittens make even routine tasks difficult for topside personnel. Waterproof outer gloves and boots may also be considered. However, regardless of the type of clothing selected, the clothing must be properly fitted (loosely worn), and kept clean and dry to maximize insulation. In planning operations for such conditions, reduced efficiency resulting in longer on-site time must be considered. Refer to the *Polar Operations Manual* for complete information on thermal protection of support personnel and equipment.

J-3.6 Ancillary Equipment. A detailed reconnaissance of the dive site will provide the planner with information that is helpful in deciding what ancillary equipment is required. Diving under ice will require special accessory equipment such as a line with lights for underwater navigation, ice cutting tools, platforms, and engine protection kits.

The method of cutting the hole through the ice depends on ice thickness and availability of equipment. Normally, two or more of the following tools are used: hand ice chipper, ice handsaw, ice auger, chain saw, thermal ice cutter, or blasting equipment. In addition, equipment to lift the ice block, remove the slush, and mark the hole is required. Sandbags, burlap bags, or pallets for the tenders to stand on are also needed. Ladders should be in place in case a tender falls into the hole.

If there is a possiblity of surface support personnel falling through the ice, floatable work platforms (e.g., inflated Zodiac boat) should be used. With such flotation equipment, in the event the ice breaks up, the operation could be continued or safely concluded.

Gasoline and diesel engines must be cold-weather modified to prevent engine freeze-up. Vibrations of engines running on the ice can be a problem, and vibration dampening platforms may be required.

J-3.7 Dive Site Shelter. Tent equipment including framing and flooring material may be required to construct a dive site shelter and a windbreak. Depending on the severity of the climate, remoteness of the site, and duration of the mission, shelters can range from small tents to steel sea-land vans and elaborate insulated huts transported to the site and erected from kits. Dive site shelters should have storage areas for dry items and a place for drying equipment. Benches should be provided for dressing divers, flooring should be installed for insulation, and heating and lighting should be adequate. In an extremely cold and dry climate, fire and inadequate ventilation are ever-present dangers. A carbon monoxide detection kit should be available and periodic checks made of all living and working spaces. Fire extinguishers shall be available in each shelter.

J-4 PREPARATION FOR DIVING

The supervisor of the dive (Diving Officer, Master Diver, or Diving Supervisor) must ensure that all personnel required to make the dive have been properly trained in ice diving techniques and are physically fit. No diver may be allowed to make the dive if, in the opinion of the Diving Supervisor, the diver is suffering from the psychological stress of an ice dive (anxiety, claustrophobia, or recklessness).

J-4.1 Dive Site Selection Considerations. The selection of the dive site will depend upon the purpose of the dive and the geographical environment of the area (ice thickness, ice surface conditions, etc.). Additionally, the diving method chosen, safe access routes, shelter location, emergency holes, and exposure of divers and required support personnel will also have a bearing on site selection.

J-4.2 Shelter. When ice diving is conducted, a shelter must be erected in close proximity to the diving site to reduce the probability of frostbite and equipment freeze-up. Normally, tents are not placed over the dive hole because it would restrict the movement of tenders and light available to the diver. However, a windbreak should be constructed. A shelter of modular tents and space heaters is ideal; although precautions must be taken to ensure that the ice beneath the shelter is not weakened. Extreme caution must be used when diving for objects, such as downed aircraft, that have fallen through the ice; the area around the original hole may be dangerously weakened.

J-4.3 The Hole. Proper equipment should be used to cut a suitable hole or holes through the ice in order to leave a clean edge around the hole. Using a sledgehammer to break through the ice is not recommended as it will weaken the surrounding ice. The hole should be a rectangle six feet by three feet, or a triangle with six-foot sides as shown in Figure J-1. The triangular hole is easier to cut, and is large enough to allow simultaneous exit by two divers. Slush and ice must be removed from the hole, not pushed under the ice surface, as it could slip back and block the hole. To assist exiting divers and improve footing for other team members on the ice surface, sand or burlap bags should be placed on the ice around the hole. Upon completion of the dive, the hole must be clearly marked to prevent

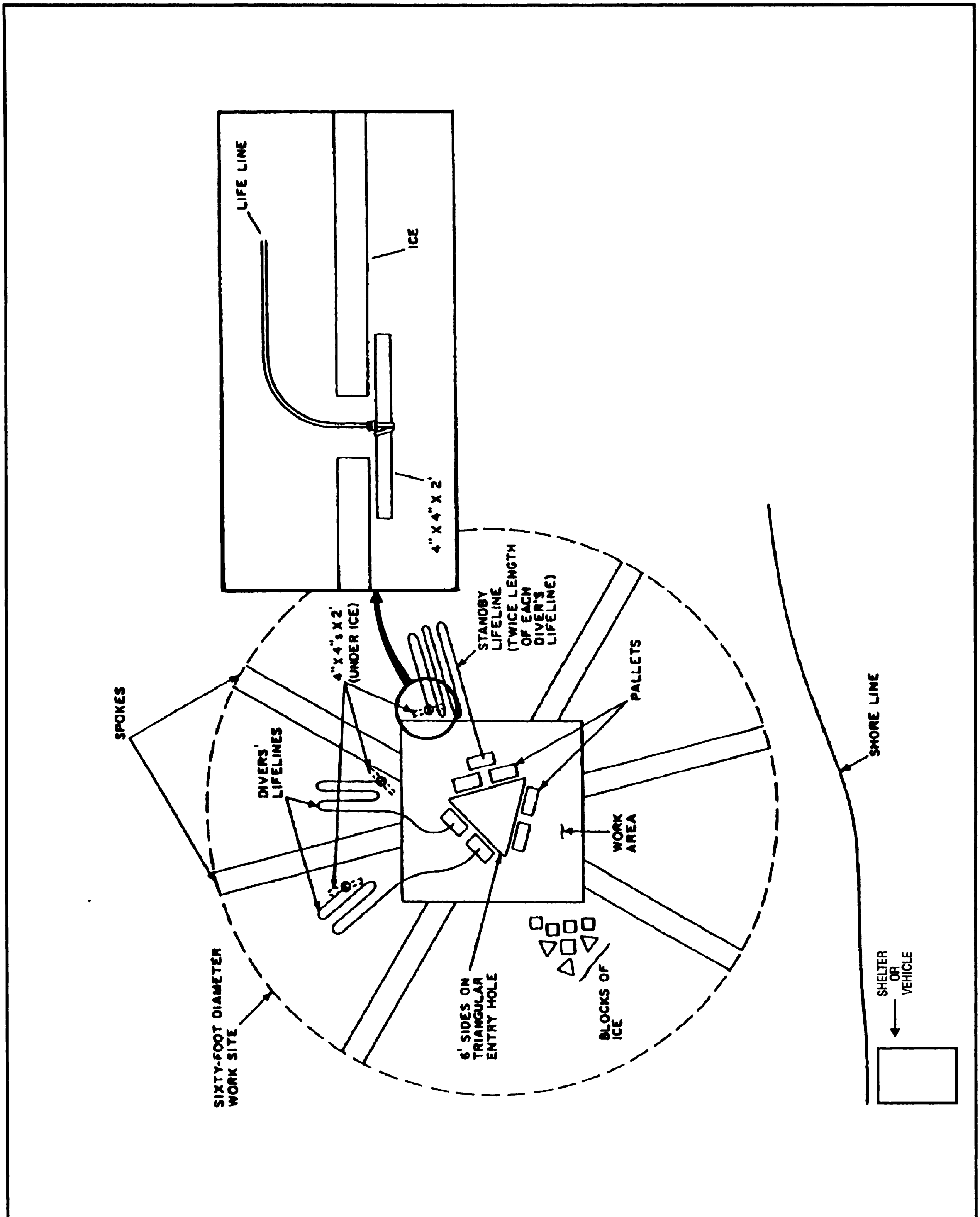


Figure J-1. Typical Ice Diving Worksite.

anyone from falling in accidentally. When possible, the pieces cut from the ice should be replaced to speed up the refreezing process.

J-4.4 Escape Holes. Escape holes provide alternative exit points and aid in searching for a lost diver. Downstream escape holes or emergency exit holes must be cut in the ice when diving in a river or bay where there is a current or tidal stream.

J-4.5 Navigation Under the Ice. A weighted line should be hung through the hole to aid the diver in retaining his bearing and sense of direction. Suspending a light at the end of the line may be helpful, as well as attaching a series of strobe lights to indicate depth. After locating the work site, a distance line should be laid from the weighted line to the work site. Another method of aiding the diver in keeping his bearings in clear water is to shovel off the snow cover on the ice around the dive site in the form of a spoked wheel (Figure J-1). When the ice and snow cover is less than 2 feet thick, the diver should be able to see the spokes leading to the dive hole located at the center of the wheel. The wheel should have a minimum diameter of 60 feet.

J-4.6 Lifelines. Use of diver tending lines is mandatory when diving under ice to aid the diver in relocating the entrance hole. A polypropylene braided or twisted line has proven to be the best lifeline. It has the advantage of floating up and away from the diver and is available in yellow, white, and orange for high visibility. A bowline or a D-ring and snap hook spliced into the lifeline is the easiest method of attaching the lifeline to the diver. The attachment of the lifeline on both ends must be absolutely secure. Do not tie the line to a vehicle, shovel, first aid box, or other portable equipment. A board, 4" x 4" x 2′ placed under the ice several yards away from the dive hole can be used to secure the bitter end of the lifeline (Figure J-1). The D-ring and snap hook allow the quickest transfer of the lifeline from diver to diver on the surface, provided the snap hooks are not frozen shut. Corrosion checks of the snap hooks should be made at frequent intervals. A wet lifeline must be kept off the bare ice to prevent it from freezing to the surface.

J-4.7 Equipment. The diver must wear a distress light, and the light should be turned on upon entering the water. Divers should not be encumbered with unnecessary equipment during cold water dives. Snorkles should be removed and knives worn on the inside of the leg to help prevent the lifeline from snagging on the diver's equipment. Personnel, divers, and tenders must handle rubber accessories such as masks and fins carefully; extreme cold causes them to become brittle.

J-5 CONDUCT OF THE DIVE

J-5.1 Buddy Diving. Diving under the ice or in extremely cold waters requires the use of paired dive partners. **Buddy diving is required, despite the fact that each diver must be surface tended. When diving through the ice, divers *shall* always be surface tended.** The life-threatening consequences of suit failure, regulator freeze-up, or other equipment problems make a solitary tended SCUBA diver particularly vulnerable. Divers must practice buddy breathing prior to conduct of the operation because of the increased possibility that buddy breathing will be required. Proficiency in the process will minimize loss of valuable time during an emergency. The use of approved cold water SCUBA equipment will minimize or eliminate freeze-up problems (see Paragraph J-3.2.1).

J-5.2 Tending the Diver. The lifeline is to be held by the tender at all times. As an additional safety measure during ice diving, the end of the lifeline must be secured to a stationary object to prevent it from falling into the entry hole should it be dropped by the tender (see Figure J-1). It is recommended that the lifeline be marked at

10-foot intervals to allow the tender and Diving Supervisor to estimate the diver's position. However, the diver's radial position can only be roughly estimated. The dive team must be thoroughly familiar with the procedures for lifeline tending in Chapter 6.

Tending line sensitivity and awareness of the diver's position by tenders may be difficult with the added factor of lifeline drag on subsurface ice formations, line drag over the lip of the under-ice hole, tending through heavy mittens, no surface bubbles, etc.

J-5.3 Standby Diver. The standby diver and tender must be immediately available. The standby diver should be kept warm until the Diving Supervisor determines that the standby diver is needed. If possible a shelter or windbreak at the hole should be used. The lifeline of the standby diver should be twice the length of the diver's lifeline in order to perform a thorough circular search. The standby diver must be dressed with the exception of fins, mask, and tanks. These will be ready to don immediately.

J-6 OPERATING PRECAUTIONS

Normal procedures generally apply to diving in extremely cold environments. However, the increased likelihood of regulator freeze-up calls for total familiarity with the buddy breathing procedures described in Chapter 5. Other precautions for operating in cold and ice-covered water follow.

J-6.1 General Precautions. Divers should be well rested, have a meal high in carbohydrates and protein, and should not consume any alcohol (alcohol dilates the blood vessels in the skin, thus increasing body heat loss).

Baths are an important health measure to prevent infectious diseases prevalent in cold environments. If necessary, the body can be sponge-bathed under clothing. After bathing, a soothing ointment or lotion should be applied to the skin to keep it soft and protect it against evaporation caused by the dry air. Shaving and washing the face should be done in the evening because shaving removes protective oils from the skin. Shaving too close can also remove some of the protective layer of the skin, promoting frostbite.

J-6.2 Ice Diving Precautions. The inconsistency and dynamics of ice conditions in any particular area can make diving operations extremely hazardous.

The movement of ice floes can be very significant over a relatively short period of time, requiring frequent relocation of dive sites and the opening of new access holes in order to work a fixed site on the sea floor. Diving from drifting ice or in the midst of broken free ice is dangerous and should be conducted only if absolutely necessary.

Differential movement of surface and subsurface pressure ridges or icebergs could close an access hole, sever a diving umbilical, and isolate or crush a diver. The opening of a rift in the ice near a dive site could result in loss of support facilities on the ice, as well as diver casualties.

J-6.3 Dressing Precautions. Thermal protection suits should be checked carefully for fabric cuts and separations.

Thermal protection suits should expose only a minimum of facial area. Mittens, boots, and seals should prevent water entry, while causing no restriction of circulation.

Wearing a knitted watchcap under the hood of a dry suit is effective in conserving body heat. With the cap pushed back far enough to permit the suit's face seal to seat properly, the head will be relatively dry and comfortable. With a properly fitting suit and all seals in place, usually the diver can be kept warm and dry in even the coldest water for short periods.

J-6.4 On-Surface Precautions. Suited divers should be protected from overheating and associated perspiring before entering the water. Overheating easily occurs when operating from a heated hut, especially if diver exertion is required to get to the dive site. The divers comfort can be improved and sweating delayed before entering the water by cooling the divers face with a damp cloth and fanning every few minutes. Perspiration will dampen undergarments, greatly reducing their thermal insulating capabilities.

While waiting to enter the water, divers should avoid sitting on or resting their feet on the ice or cold floor of a hut. Even in an insulated hut, the temperature at the floor may be near freezing.

Time on the surface with the diver suited, but relatively inactive, should be minimized to prevent chilling of the diver. This can also result in cooling metal components of the diving gear, such as suit valves and SCUBA regulators, below the freezing point and subsequent icing of the parts upon entering the water. Dressing rehearsals prior to diving will help minimize surface delays.

When operating from an open boat, heavy parkas or windbreakers should be worn over the exposure suits.

When operating at the surface in newly formed ice, care should be taken to avoid cutting exposed facial skin. Such wounds occur easily and, although painless because of the numbness of the skin, usually bleed profusely.

Diving from a beach and without a support vessel should be limited to a distance that allows the divers to return to the beach if the suit floods.

Extreme caution must be exercised when diving near ice keels in polar regions as they will often move with tidal action, wind, or current. In doing so, they can foul umbilicals and jeapardize the divers' safety.

J-6.5 In-Water Precautions. Because severe chilling can result in impaired judgement, the tasks to be performed under water must be clearly identified, practiced, and kept simple.

A dive should be terminated upon the onset of involuntary shivering or severe impairment of manual dexterity.

should the exposure suit tear or flood, the diver should surface immediately, regardless of the degree of flooding. The extreme chilling effect of frigid water can cause thermal shock within minutes, depending on the extent of flooding.

Divers and especially Diving Supervisors must be aware of the cumulative thermal effect of repetitive diving. A thermal debt can accumulate over successive diving days, resulting in increased fatigue and reduced performance. This progressive hypothermia associated with long, slow cooling of the body appears to cause significant core temperature drop before shivering and heat production begins.

J-6.6 Postdive Precautions. Upon exiting cold water, a diver will probably be fatigued and greatly susceptible to additional chilling. If a wet suit was worn, immediate flushing with warm water upon surfacing will have a comforting, heat-replacing effect. Facilities must be provided which allow the diver to dry off in a comfortable, dry, and relatively warm environment to regain lost body heat. The diver should remove any wet dress, dry off, and don warm protective clothing as soon as possible. Personnel should have warm, dry clothing, blankets, and hot non-acoholic beverages available to them.

J-7 EMERGENCY PROCEDURES

J-7.1 Lost Diver. should a diver become detached from the lifeline and unable to locate the entrance hole, the diver should take the following actions.

(1) Ascend to the underside of the ice.

(2) Remove weight belt and allow it to drop.

(3) Fix the point of knife into the ice to maintain position.

(4) Remain in a vertical position, to maximize vertical profile and thereby snag the searching standby diver's lifeline.

(5) Watch for lifeline and the lifeline of the standby diver, and wait for the standby diver to arrive. The lost diver MUST NOT attempt to relocate the hole. The diver must remain calm and watch for the standby diver.

J-7.2 Search. As soon as the tender fails to get a response from the diver, the tender must notify the Diving Supervisor immediately. The following procedures are to be implemented at once.

(1) Immediately recall all other divers.

(2) The Diving Supervisor must estimate the probable location of the lost diver by assessing the diver's speed and direction of travel.

(3) As directed by the Diving Supervisor, the standby diver enters the water and swims in the indicated direction, a distance equal to twice that believed to be covered by the lost diver. The distance may be the full extent of the standby diver's lifeline since it is twice as long as the lost diver's lifeline.

(4) The tender must keep the standby diver's lifeline taut.

(5) A circular sweep is conducted by the standby diver.

(6) When the lifeline snags on the lost diver, the standby diver swims toward the diver signaling the tender to take up slack.

(7) Upon locating the lost diver, the standby diver assists the diver back to the hole.

(8) should the first sweep fail, it should be repeated only once before moving the search to the most likely emergency hole.

J-7.3 Hypothermia. When diving in cold water, hypothermia may predispose the diver to decompression sickness. Hypothermia is easily diagnosed. The hypothermic diver loses muscle strength, the ability to concentrate, and may become irrational or confused. The victim may shiver violently, or, with severe hypothermia, shivering may be replaced by muscle rigidity. Profound hypothermia may so depress the heartbeat and respiration that the victim appears dead. However, a diver should not be considered dead until the diver has been rewarmed and all resuscitation attempts have been proven to be unsuccessful.

Hypothermia demands immediate treatment and prompt evacuation to a medical facility. A hypothermic diver must not be allowed to walk; i.e., the diver should be transported in a horizontal position. Improper handling of the diver can cause dangerous rhythms of the heart and a drop in the body core temperature, known as after drop. See Chapter 8, Diving Medicine, for an in-depth discussion of the treatment of hypothermia.

APPENDIX K

DIVER CANDIDATE PRESSURE TEST

K-1 INTRODUCTION

All U.S. Navy diver candidates must be physically qualified in accordance with the Manual of the Medical Department (Art. 15-66). Candidates must also pass a pressure test before they are eligible for diver training. This test may be conducted at any Navy certified recompression chamber, provided it is administered by qualified chamber personnel.

K-2 CANDIDATE

The candidate must demonstrate the ability to equalize pressure in both ears to a depth of 60 fsw.

K-3 INSIDE TENDER

The inside tender(s) should be a qualified First Class Diver or above.

K-4 PROCEDURE

1. Candidates must undergo a diving physical examination by a Navy Medical Officer in accordance with *The Manual of the Medical Department*, Art. 15-66, and be qualified to undergo the test.

2. The candidate(s) and the tender enter the recompression chamber and are pressurized to 60 fsw on air, at a rate of 75 fpm or less as tolerated by the occupants.

3. If a candidate cannot complete the descent the chamber is stopped and the candidate is placed in the outer lock for return to the surface.

4. Stay at 60 fsw for at least a 10 minute total bottom time.

5. Ascend to surface following standard air decompression procedures.

6. All candidates will remain at the immediate chamber site for a minimum of 15 minutes and at the test facility for one hour. Candidates or tenders who must return to their command via air travel must proceed in accordance with Paragraph 7-6.2.

References:

(a) *Navy Military Personnel Manual*, Art. 1410380

(b) *Manual of the Medical Department*, Art. 15-66

(c) *SECNAVINST 12000.2A*

APPENDIX L

COMPRESSED AIR AND OXYGEN - PURITY STANDARDS AND CONTAINER HANDLING

L-1 AIR DIVING GASES PURITY STANDARDS

L-1.1 Air, Compressed for Breathing Purposes. Purity standards for diver's breathing air shall conform to those specified in Table L-1. When a cylinder of compressed air is obtained from commercial sources, it must conform to the purity standards of Source One Grade A air specified in FED SPEC BB-A-1034. Breathing air shall be sampled at intervals not to exceed six months. To monitor diver breathing air purity, NAVSEASYSCOM has established an air sampling program (see Appendix I.) In addition to regularly scheduled sampling, analysis of air samples can be obtained under this program on an as-needed basis.

L-1.2 Oxygen. Purity Standards for oxygen shall conform to Military Specification MIL-O-27210; Oxygen, Aviator's Breathing, Liquid Gas as listed in Table L-2. Type One (gaseous) oxygen and Type Two (liquid) oxygen, when gasified, may be used for diving/hyperbaric breathing oxygen. Type One oxygen and Type Two oxygen, when gasified, shall contain not less than 99.5 percent pure oxygen by volume. The remainder, except for moisture and the minor constituents listed in Table L-2, shall be argon and nitrogen. Moisture shall not exceed 0.005 milligrams of water vapor per liter of gas at 70°F (21.1°C) and 760 millimeters of mercury. The oxygen shall be odor free. Type Two oxygen shall contain no particles with any dimension larger than 1,000 microns, or fibers longer than 6,000 microns. The total solids contained in the liquid shall not exceed 1.0 milligram per liter.

L-2 GAS ANALYSIS

The precise determination of the type and concentration of the constituents of breathing gas is of vital importance in diving operations. As has been shown in Chapter Three, adverse physiological reactions can occur whenever exposure time and concentrations of various components in the breathing atmosphere vary from prescribed limits. Concern for the quality of the breathing gas is important in both air and mixed-gas diving. In air diving the basic gas composition is fixed and the primary consideration is directed toward determination of gaseous impurities that may be present in the air supply (i.e. carbon monoxide, hydrocarbons) and the effects of inadequate ventilation (carbon dioxide build up). For further information on gas analysis, see Appendix C of Volume Two of the *U.S. Navy Diving Manual.*

L-3 CONTAINER HANDLING

Compressed gas container handling, usage, transport, and storage procedures are regulated by NAVSEA S9086-SX-STM-000, *Naval Ships' Technical Manual,* Chapter 550, Industrial Gases, Generating, Handling, and Storage. Compressed gas containers must be handled with care to prevent explosion, structural damage to the container, and contamination or misidentification of the contents. Appendix C of Volume Two of the *U.S. Navy Diving Manual* has additional information concerning container handling.

Table L-1. Air Purity Standards.

Constituent	USN Diving Manual	FED SPEC BB-A-1034
Oxygen (O_2) (percent by volume)	20-22%	20-22%
Carbon Dioxide (CO_2) (by volume)	1,000 ppm (max)	500 ppm (max)
Carbon Monoxide (CO) (by volume)	20 ppm (max)	10 ppm (max)
Total Hydrocarbons (as CH_4) (by volume)	25 ppm (max)	25 ppm (max)
Oil, Mist, Particulates (weight/volume)	5 mg/m^3 (max)	.005 mg/l (max)
Odor	Not Objectionable	Not pronounced or objectionable
Separated Water	Not Specified	None
Total Water (weight/volume)	Not Specified	0.02 mg/l (max)
Nitrogen Dioxide (NO_2) (by volume)	Not Specified	2.5 ppm (max)
Nitrous Oxide (N_2O) (by volume)	Not Specified	2.0 ppm (max)
Sulfur Dioxide (SO_2) (by volume)	Not Specified	2.5 ppm (max)
Halogenated Compounds (by volume) Refrigerants Solvents	 Not Specified Not Specified	 2.0 ppm (max) 0.2 ppm (max)
Acetylene (C_2H_2)	Not Specified	0.1 ppm (max)
Ethylene (C_2H_4)	Not Specified	0.4 ppm (max)

Table L-2. Oxygen Purity Standards.

Constituent	Maximum Concentration (ppm by volume)	
	Type 1	Type 2
Carbon Dioxide (CO_2)	10.0	5.00
Methane (CH_4)	50.0	25.00
Acetylene (C_2H_2)	0.1	0.05
Ethylene (C_2H_4)	0.4	0.20
Ethane (C_2H_6) and other hydrocarbons)	6.0 (C_2H_6 equivalent)	3.00 (C_2H_6 equivalent)
Nitrous Oxide (N_2O)	4.0	2.0
Halogenated Compounds Refrigerants (Freons, etc.) Solvents (Trichloroethylene, Carbon Tetrachloride, etc.)	 2.0 0.2	 1.00 0.10
Other (each discernible from background noise on infrared spectrophotometer)	0.2	0.10

APPENDIX M

FIRST AID

M-1 INTRODUCTION

This appendix, covering one-man cardiopulmonary resuscitation, control of bleeding, and shock treatment, is intended as a quick reference for individuals trained in first aid and Basic Life Support. Complete descriptions of all Basic Life Support techniques are available through your local branch of the American Heart Association, or at the American Heart Association, National Center, 7320 Greenville Avenue, Dallas, TX 75231. Further information on the control of bleeding and treatment for shock is in the *Hospital Corpsman 3 & 2 manual,* NAVEDTRA 10669-C.

Periodic recertification according to current guidelines in Basic Life Support is mandatory for all Navy Divers. Training can be requested through your local medical command, or directly through your local branch of the American Heart Association.

In any injury or accident there are four medical actions that must be taken immediately; these actions cannot be postponed until medical personnel arrive. In order of priority, they are:

(1) Ensure a clear airway.

(2) Restore breathing.

(3) Ensure heart function.

(4) Stop massive bleeding.

The first action must be to establish a clear airway. Either a head-tilt/chin-lift or jaw-thrust maneuver may be used. If spontaneous breathing is not resumed immediately, two quick breaths should be given to the victim while watching for the chest to rise. Check the victim's pulse. If a pulse is present, continue mouth-to-mouth resuscitation as long as necessary. If a pulse is absent, combined pulmonary and cardiac resuscitation is performed, as described in Paragraphs M-2 and M-3. Severe bleeding is controlled at the same time these actions are taken.

If the rescuer is not alone, one person should be sent to call the local emergency telephone number, activating the EMS system if not previously done.

Having taken these actions, a more thorough diagnosis of the problem can be made. From that point, the person helping a severely injured diver can best serve the patient by giving protection from further harm. Strive to maintain breathing, heartbeat, and blood circulation in a stable condition. Other treatment, such as placement in a recompression chamber, may be concurrent with these procedures.

M-2 PULMONARY RESUSCITATION

Cessation of breathing, leading to asphyxia, can result in cell damage and death very quickly. The problem may be the result of a number of factors that must be considered in conjunction with any attempt to restore breathing. These are:

(1) Mechanical blockage of the air passage by water, vomitus, blood clots, or foreign bodies.

(2) Blockage of the air passages by abnormal swelling and increased secretions of mucous membranes which may be caused by allergic reactions or severe inflammation.

(3) Dysfunction of the respiratory muscles or disruption of the chest breathing action which may be caused by trauma.

(4) Paralysis of the respiratory system as a result of nerve injury caused by:

(a) Damage to the spinal cord or brain

(b) Electric shock

(5) Cardiac arrest.

M-2.1 Clearing the Airway. The first step in resuscitation is clearing the airway. If the unconscious victim cannot be ventilated after two quick breaths or if a conscious person is choking, foreign objects, secretions, or vomitus may be obstructing the airway. All diving personnel should be familiar with the two methods of removing airway obstructions: manual thrusts and finger sweeps.

(1) **Manual Thrusts (Heimlich Maneuver)** - Use either the abdominal or chest thrust. Stand behind the patient, wrapping arms around the victim's chest or waist. One hand should form a fist placed against the victim's body and covered with the other hand (see Figure M-1). The fist must be well below the tip of the breastbone for abdominal thrusts or in the center of the breastbone for chest thrusts. Each new thrust should be a separate and distinct movement. The thrusts should be repeated until the foreign body is expelled or the victim becomes unconscious. If unconsciousness does occur, the victim should be placed in the supine position with the face up. The rescuer should kneel astride the victim's thighs and place the heel of one hand against the victim's abdomen, in the midline slightly above the navel and well below the tip of the xiphoid, and the second hand directly on top of the first. The rescuer should

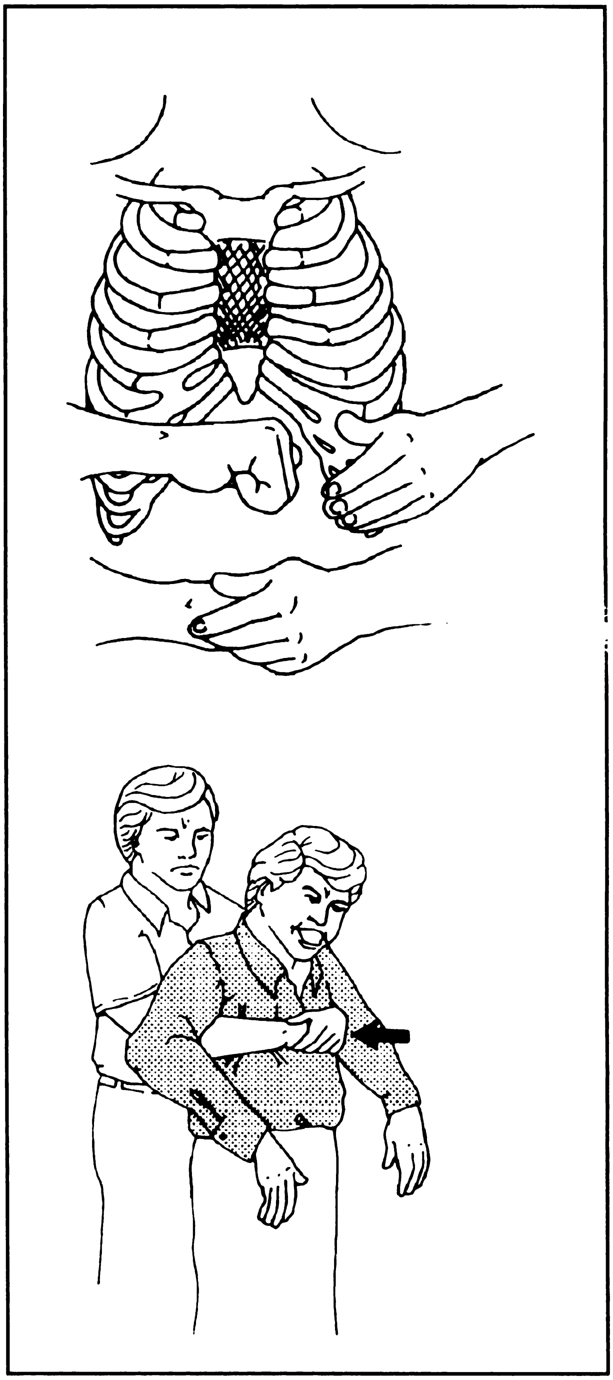


Figure M-1. Clearing the Airway (Heimlich Maneuver). Use either the abdominal or chest thrust. Stand behind the patient and wrap arms around the victim's chest or waist. One hand should form a fist placed against the victim's body and covered with the other hand. The fist must be well below the tip of the breastbone for abdominal thrusts or in the center of breastbone for chest thrusts. It may be necessary the thrust 6 to 10 times to clear the airway. In the abdominal thrust, the force is applied inward and upward; in chest thrusts, the thrust is applied straight back to the victim's spine.

then press into the abdomen with a quick upward thrust. If the rescuer is in the correct position, he has a natural midabdominal position and is thus unlikely to direct the thrust to the right or left. A rescuer too short to reach around the waist of a victim who is conscious can use this technique. The rescuer can use his body weight to perform the maneuver. It may be necessary to repeat the thrust six to ten times to clear the airway. In the abdominal thrust, the force is applied inward and upward; in chest thrusts, the force is applied straight back to the victim's spine. Be careful not to use excessive force; some individuals are capable of breaking ribs or causing abdominal trauma if excessive force is used.

(2) **Finger Sweep -** The finger sweep is used to clear the victim's throat of any obstruction in the upper esophagus. With the victim's head up, open the victim's mouth by grasping the tongue and lower jaw between the thumb and fingers (tongue-jaw lift). Insert the index finger down the side of the cheek and deeply into the throat at the base of the tongue. Use a hooking action to dislodge foreign material, being careful not to force it further back into the throat. The finger sweep is only used on unconscious victims.

The two techniques described above are used together as follows:

(1) Identify the airway obstruction and ask the victim if he or she is choking.

(2) Apply the manual thrust until the foreign body is expelled or the victim becomes unconscious.

(3) If the victim is unconscious, open the victim's mouth and perform the finger sweep.

(4) Open the airway and attempt rescue breathing.

(5) If unable to ventilate, perform additional (six to ten) subdiaphragmatic abdominal thrusts (Heimlich maneuver).

(6) Open the mouth and perform finger sweep.

(7) Attempt to ventilate.

(8) Repeat the sequence of subdiaphragmatic abdominal thrusts, finger sweep, and attempt to ventilate.

(9) Persist in these efforts as long as necessary.

(10) A second person, if available, should attempt to locate medical assistance and activate the EMS.

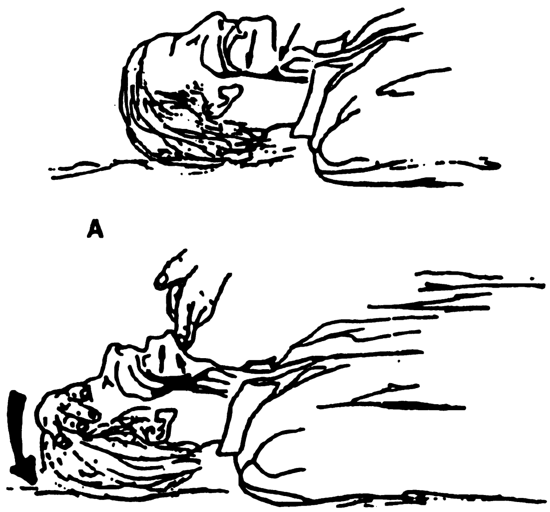
If the victim is not breathing independently, mouth-to-mouth resuscitation should be started once a clear airway has been established. Manual resuscitation should be continued until a mechanical resuscitator is made available.

M-2.2 Mouth-To-Mouth Resuscitation. Of the several methods of manual pulmonary resuscitation that have been developed, the method of choice for initial resuscitation (until a mechanical resuscitator is available) is the mouth-to-mouth technique (Figure M-2). The mouth-to-pocket mask technique is also good and is preferred in patients who are suspected of having a contagious disease.

In unconscious victims, use of an airway device helps to maintain a clear air passage. The device may cause the patient to gag and vomit if left in

MOUTH-TO-MOUTH RESUSCITATION

A - To open the airway, place one hand on the victim's forehead and place the fingers of the other hand under the bony part of the lower jaw near the chin and lift to bring the chin forward and the teeth almost to occlusion, thus supporting the jaw and helping to tilt the head back. The fingers must not press deeply into the soft tissue under the chin, which might obstruct the airway. The thumb should not be used for lifting the chin. The mouth should not be completely closed (unless mouth-to-nose breathing is the technique of choice for that particular victim). When mouth-to-nose ventilation is indicated, the hand that is already on the chin can close the mouth by applying increased force and in this way provide effective mouth-to-nose ventilation. If the victim has loose dentures, head-tilt/chin-lift maintains their position and makes a mouth-to-mouth seal easier. Dentures should be removed if they cannot be managed in place.



A

B

C

B - To assess the presence or absence of spontaneous breathing, the rescuer should place his or her ear over the victim's mouth and nose while maintaining an open airway. Then while observing the victim's chest, the rescuer should (1) look for the chest to rise and fall; (2) listen for air escaping during exhalation; (3) feel for the flow of air. If the chest does not rise and fall and no air is exhaled, the victim is breathless. This evaluation procedure should take only 3 to 5 seconds.

It should be stressed that, although the rescuer may notice that the victim is making respiratory efforts, the airway may still be obstructed and opening the airway may be all that is needed. If the victim resumes breathing, the rescuer should continue to help maintain an open airway.

C - Keeping the airway open by the head-tilt/chin-lift maneuver, the rescuer gently pinches the nose closed using the thumb and index finger of the hand on the forehead, thereby preventing air from escaping through the victim's nose. The rescuer takes a deep breath and seals his or her lips around the outside of the victim's mouth, creating an airtight seal; then the rescuer gives 2 full breaths.

If a pulse is present but there is no breathing, rescue breathing should be initiated at a rate of 12 times per minute (once every 5 seconds) after initial 2 breaths of 1 to 1½ seconds each.

Figure M-2. Mouth-to-Mouth Resuscitation (Rescue Breathing).

place when the victim starts to respond to resuscitation efforts.

Mouth-to-mouth resuscitation must be continued without interruption. If the principal attendant becomes fatigued, a relief attendant must take over without breaking the rhythm. If the patient shows any signs of spontaneous breathing, the timing of the cycle should be adjusted to match the patient's effort. If the patient starts to breathe independently, the patient should be watched closely and resuscitation resumed if the effort falters or becomes too feeble.

Once mouth-to-mouth resuscitation has begun, treatment of other injuries can be administered. The patient should be kept lying down and made as comfortable as possible: wet clothing should be removed, and the patient should be kept warm. No attempt should be made to give any food, drink, or medicine by mouth until the patient is fully conscious. The patient must be examined by a medical officer as soon as possible, even if no residual ill-effects from the emergency are apparent.

M-2.3 Mechanical Resuscitation. A bag resuscitator (a simple, hand-powered device) can be substituted for mouth-to-mouth resuscitation when it is immediately available.

NOTE

A bag resuscitator is more effective than mouth-to-mouth techniques only if individuals are trained to use the mask properly. Individuals not properly trained in the use of the mask should continue mouth-to-mouth resuscitation until qualified help arrives.

NOTE

The bag resuscitator must be constructed of a clear, flexible material, and should allow for easy cleaning.

The bag resuscitator allows the use of oxygen to assist respiration and is readily employed in recompression chambers.All diving units should be equipped with a bag-type resuscitator, and all members of the diving team must be thoroughly familiar with the proper operation of the apparatus.

The mask of the mechanical bag resuscitator is held over the mouth and nose with one hand while the bag is squeezed and released in a rhythmic manner with the other hand. The operator should check the victim's chest movement to ensure that air is actually moving in and out of the lungs. A clear airway can be ensured by keeping the fingers of the mask hand on the long part of the jaw and by using the little finger placed behind the angle of the jaw to lift the jaw upward. If the pupil of the eye constricts when a light is shined in it, the brain is receiving an adequate oxygen level.

The mechanical bag resuscitator may also be used with a pure oxygen supply. Operational procedures are identical except that oxygen rather than air is forced into the victim's lungs.

M-3 CARDIAC RESUSCITATION

Cardiac arrest may result from electric shock, asphyxia, or from a combination of factors such as hypoxia, shock, or embolism. In the immediate emergency situation, the cause is not as important as the effort to restore or mechanically reproduce the heartbeat. Arrest of heart action can be recognized by the absence of a pulse in the major vessels. If the heartbeat has been interrupted more than four minutes, irreversible damage to the brain and other vital organs can result.

Closed-chest cardiac massage is a method for artificially continuing the flow of blood to the central nervous system and vital organs. Closed-chest compression may result in a spontaneous resumption of the heartbeat. If it does not, compression is continued while the patient is moved to a medical facility. Resuscitative effort should be continued until:

(1) effective spontaneous circulation and ventilation have been restored,

(2) a medical officer assumes responsiblity and directs termination, or

(3) the rescuer is totally exhausted and unable to continue.

In closed-chest cardiac compression, the operator applies pressure on the lower half of the victim's breastbone, which squeezes the heart and circulates the blood. At the same time, the victim's lungs must be ventilated using mouth-to-mouth resuscitation or, preferably, 100-percent oxygen administered with a bag resuscitator. Cardiopulmonary resuscitation will help to offset the hypoxia that is a natural result of cardiac arrest; without circulation of blood, cells of the brain and the rest of the body will die due to lack of oxygen. A detailed procedure for performing cardiopulmonary resuscitation is described in Figure M-3.

M-4 CONTROL OF MASSIVE BLEEDING

Massive bleeding must be controlled immediately. If the victim also requires resuscitation, the two problems must be handled simultaneously. Bleeding may involve veins or arteries; the urgency and method of treatment will be determined in part by the type and extent of the bleeding.

M-4.1 External Arterial Hemorrhage.

Arterial bleeding can usually be identified by bright red blood, gushing forth in jets or spurts that are synchronous with the pulse. The first measure used to control external arterial hemorrhage is direct pressure on the wound.

M-4.1.1 Direct Pressure. Pressure is best applied with sterile compresses, placed directly and firmly over the wound. In a crisis, however, almost any material can be used. If the material used to apply direct pressure soaks through with blood, apply additional material on top; do not remove the original pressure bandage. Elevating the extremity also helps to control bleeding. If direct pressure cannot control bleeding, it should be used in combination with pressure points.

M-4.1.2 Pressure Points. Bleeding can often be temporarily controlled by applying hand pressure to the appropriate pressure point. A pressure point is a place where the main artery to the injured part lies near the skin surface and over a bone. Apply pressure at this point with the fingers (digital pressure) or with the heel of the hand; no first aid materials are required. The object of the pressure is to compress the artery against the bone, thus shutting off the flow of blood from the heart to the wound.

There are 11 principal points on each side of the body where hand or finger pressure can be used to stop hemorrhage. These points are shown in Figure M-4. If bleeding occurs on the face below the level of the eyes, apply pressure to the point on the mandible. This is shown in Figure M-4 (a). To find this pressure point, start at the angle of the jaw and run your finger forward along the lower edge of the mandible until you feel a small notch. The pressure point is in this notch.

If bleeding is in the shoulder or in the upper part of the arm, apply pressure with the fingers behind the clavicle. You can press down against the first rib or forward against the clavicle - either kind of pressure will stop the bleeding. This pressure point is shown in Figure M-4(b).

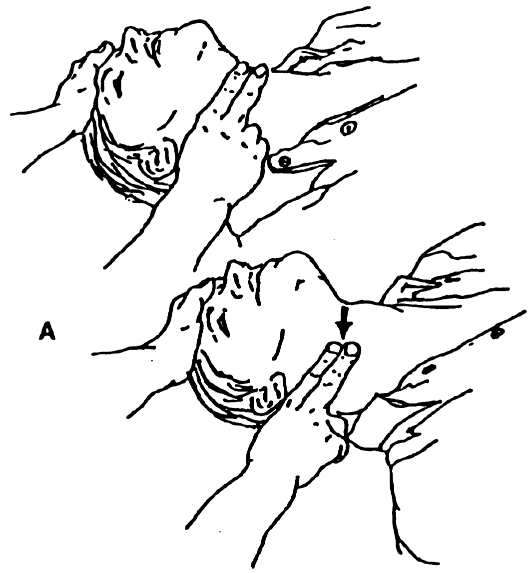
Bleeding between the middle of the upper arm and the elbow should be controlled by applying digital pressure in the inner (body) side of the arm, about halfway between the shoulder and the elbow. This compresses the artery against

CARDIOPULMONARY RESUSCITATION (CPR)

Cardiac arrest is recognized by pulselessness in the large arteries of the unconscious victim. The pulse check should take 5 to 10 seconds, and the carotid artery should be used. It lies in a groove created by the trachea and the large strap muscles of the neck. While maintaining head-tilt with one hand on the forehead, the rescuer locates the victim's larynx with two or three fingers of the other hand. The rescuer then slides these fingers into the groove between the trachea and the muscles at the side of the neck where the carotid pulse can be felt. The pulse area must be pressed gently to avoid compressing the artery.

A - Airway Assessment: determine unresponsiveness (tap gently, shake, and shout), (1) call for help, (2) position the victim, and (3) open the airway by the head-tilt/chin-lift maneuver.

Breathing-Assessment: determine pulselessness. If the victim is breathing, (1) monitor breathing, (2) maintain an open airway, and (3) call for help (if not done previously). If the victim is not breathing, perform rescue breathing by giving two initial breaths. If unable to give two breaths, (1) reposition the head and attempt to ventilate again, and (2) if still unsuccessful, perform the foreign-body airway obstruction sequence. If successful, continue to the next step.



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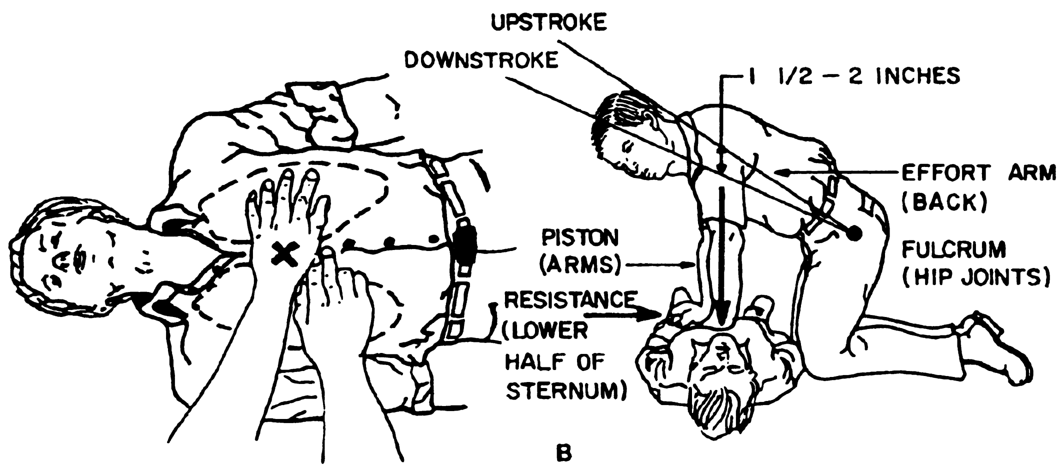

B

B - Circulation Assessment: determine pulselessness. (1) If pulse is present, continue rescue breathing at 12 times per minute. (2) If pulse is absent, begin external chest compression: (a) Locate proper hand position. (b) Perform 15 external chest compressions at a rate of 80 to 100 per minute. (c) Open the airway and deliver two rescue breaths. (d) Locate the proper hand position and begin 15 more compressions at a rate of 80 to 100 per minute. (e) Perform four complete cycles of 15 compressions and two ventilations. Reevaluate the patient. Do not interrupt CPR for more than seven seconds, if possible.

Figure M-3. Cardiopulmonary Resuscitation (CPR).

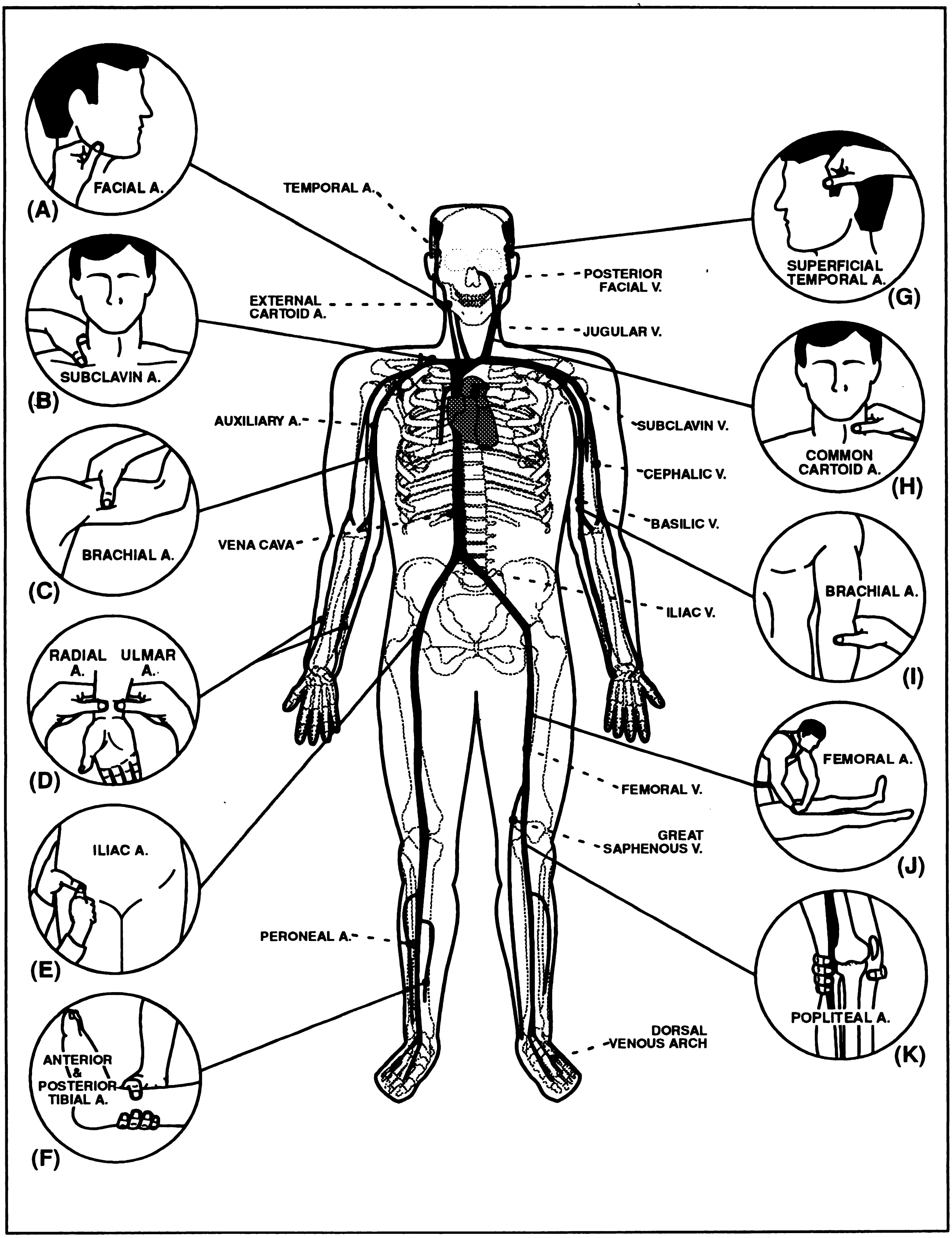

Figure M-4. Pressure Points.

the bone of the arm. The application of pressure at this point is shown in Figure M-4 (c). Bleeding from the hand can be controlled by pressure at the wrist, as shown in Figure M-4 (d). If it is possible to hold the arm up in the air, the bleeding will be relatively easy to stop.

Figure M-4 (e) shows how to apply digital pressure in the middle of the groin to control bleeding from the thigh. The artery at this point lies over a bone and quite close to the surface, so pressure with your fingers may be sufficient to stop the bleeding.

Figure M-4 (f) shows the proper position for controlling bleeding from the foot. As in the case of bleeding from the hand, elevation is helpful in controlling the bleeding.

If bleeding is in the region of the temple or the scalp, use your finger to compress the main artery to the temple against the skull bone at the pressure point just in front of the ear. Figure M-4 (g) shows the proper position.

If the neck is bleeding, apply pressure below the wound, just in front of the prominent neck muscle. Press inward and slightly backward, compressing the main artery of that side of the neck against the bones of the spinal column. The application of pressure at this point is shown in Figure M-4 (h). Do not apply pressure at this point unless it is absolutely essential, since there is a great danger of pressing on the windpipe and thus choking the victim.

Bleeding from the lower arm can be controlled by applying pressure at the elbow, as shown in Figure M-4 (i).

As mentioned before, bleeding in the upper part of the thigh can sometimes be controlled by applying digital presure in the middle of the groin, as shown in Figure M-4 (e). Sometimes, however, it is more effective to use the pressure point of the upper thigh, as shown in Figure M-4 (j). If you use this point, apply pressure with the closed fist of one hand and use the other hand to give additional pressure. The artery at this point is deeply buried in some of the heaviest muscle of the body, so a great deal of pressure must be exerted to compress the artery against the bone.

Bleeding between the knee and the foot may be controlled by firm pressure at the knee. If pressure at the side of the knee does not stop the bleeding, hold the front of the knee with one hand and thrust your fist hard against the artery behind the knee, as shown in Figure M-4 (k). If necessary, you can place a folded compress or bandage behind the knee, bend the leg back, and hold it in place by a firm bandage. This is a most effective way of controlling bleeding, but it is so uncomfortable for the victim that it should be used only as a last resort.

You should memorize these pressure points so that you will know immediately which point to use for controlling hemorrhage from a particular part of the body. Remember, the correct pressure point is that which is **(1) NEAREST THE WOUND,** and **(2) BETWEEN THE WOUND AND THE MAIN PART OF THE BODY.**

It is very tiring to apply digital pressure, and it can seldom be maintained for more than 15 minutes. Pressure points are recommended for use while direct pressure is being applied to a serious wound by a second resscuer, or after a compress, bandgage, or dressing has been applied to the wound, since it will slow the flow of blood to the area, thus giving the direct pressure technique a better chance to stop the hemorrhage. It is also recommended as a stopgap measure until a pressure dressing or a tourniquet can be applied.

M-4.1.3 Tourniquet. A tourniquet is a constricting band that is used to cut off the supply of blood to an injured limb. Use a tourniquet only if the control of hemorrhage by other means proves to be difficult or impossible. A tourniquet must always be applied ABOVE the wound, i.e., towards the trunk, and it must be applied as close to the wound as practical.

Basically, a tourniquet consists of a pad, a band, and a device for tightening the band so that the blood vessels will be compressed. It is best to use a pad, compress, or similar pressure object, if one is available. It goes under the band. It must be placed directly over the artery or it will actually decrease the pressure on the artery and thus allow a greater flow of blood. If a tourniquet placed over a pressure object does not stop the bleeding, there is a good chance that the pressure object is in the wrong place. If this occurs, shift the object around until the tourniquet, when tightened, will control the bleeding. Any long flat material may be used as the band. It is important that the band be flat: belts, stockings, flat strips of rubber, or neckerchiefs may be used; but rope, wire, string, or very narrow pieces of cloth should not be used because they cut into the flesh. A short stick may be used to twist the band, tightening the tourniquet. Figure M-5 shows how to apply a tourniquet.

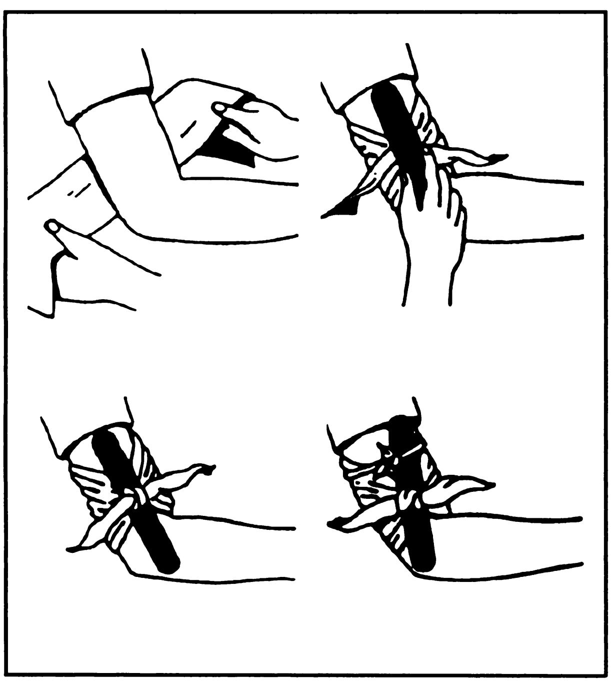

Figure M-5. Applying a tourniquet.

To be effective, a tourniquet must be tight enough to stop the arterial blood flow to the limb, so be sure to draw the tourniquet tight enough to stop the bleeding. However, do not make it any tighter than necessary.

After you have brought the bleeding under control with the tourniquet, apply a sterile compress or dressing to the wound and fasten it in position with a bandage.

Here are the points to remember about using a tourniquet:

1. Don't use a tourniquet unless you can't control the bleeding by any other means.

2. Don't use a tourniquet for bleeding from the head, face, neck, or trunk. Use it only on the limbs.

3. Always apply a tourniquet **ABOVE THE WOUND** and as close to the wound as possible. As a general rule, do not place a tourniquet below the knee or elbow except for complete amputations. In certain distal areas of the extremities, nerves lie close to the skin and may be damaged by the compression. Furthermore, rarely does one encounter bleeding distal to the knee or elbow that requires a tourniquet.

4. Be sure you draw the tourniquet tight enough to stop the bleeding, but don't make it any tighter than necessary. The pulse beyond the tourniquet should disappear.

5. Don't loosen a tourniquet after it has been applied. Transport the victim to a medical facility that can offer proper care.

6. Don't cover a tourniquet with a dressing. If it is necessary to cover the injured person in some way, **MAKE SURE** that

all the other people concerned with the case know about the tourniquet. Using crayon, skin pencil, or blood, mark a large "T" on the victim's forehead or on a medical tag attached to the wrist.

M-4.2 External Venous Hemorrhage. Venous hemorrhage is not as dramatic as severe arterial bleeding, but if left unchecked, can be equally serious. Venous bleeding is usually controlled by applying direct pressure on the wound.

M-4.3 Internal Bleeding. The signs of external bleeding are obvious, but the first aid team must be alert for the possibility of internal hemorrhage. Victims subjected to crushing injuries, heavy blows, or deep puncture wounds should be observed carefully for signs of internal bleeding. Signs usually present include:

- Moist, clammy, pale skin
- Feeble and very rapid pulse rate
- Lowered blood pressure
- Faintness or actual fainting
- Blood in stool, urine, or vomitus

Internal bleeding can be controlled only by trained medical personnel, and often only under hospital conditions. Efforts in the field are generally limited to replacing lost blood volume through intravenous infusion of saline, Ringer's Lactate or other fluids, and administration of oxygen. Rapid evacuation to a medical facility is essential.

M-5 SHOCK

Shock may occur with any injury, and will certainly be present to some extent with serious injuries. Shock is caused by a loss of blood flow, resulting in a drop of blood pressure and decreased circulation. This drop in the quantity of blood flowing to the tissues can have serious, permanent effects, including death, if not treated.

M-5.1 Signs and Symptoms of Shock. Shock can be recognized from the following signs and symptoms.

- Respiration shallow, irregular, labored
- Eyes vacant (staring), lackluster, tired-looking
- Pupils dilated
- Cyanosis (blue lips, fingernails)
- Skin pale or ashen gray; wet, clammy, cold
- Pulse weak and rapid, or may be normal
- Blood pressure drop
- Possible retching, vomiting, nausea, hiccups
- Thirst

M-5.2 Treatment. Shock must be treated before any other injuries or conditions except breathing and circulation obstructions, and profuse bleeding. Proper treatment involves caring for the whole patient, not limiting attention to only a few of the disorders. The following steps must be taken to treat a patient in shock.

(1) **Ensure adequate breathing -** If the patient is breathing, maintain an adequate airway by tilting the head back properly. If the patient is not breathing, establish an airway and restore breathing through some method of pulmonary resuscitation (refer to Paragraph M-2). If both respiration and circulation have stopped, insti-

tute cardiopulmonary resuscitation measures (refer to Paragraph M-3).

(2) **Control bleeding -** If the patient has bleeding injuries, use direct pressure pressure points, or a tourniquet, as required (refer to paragraph M-4).

(3) **Administer oxygen -** Remember that an oxygen deficiency will be caused by the reduced circulation. Administer 100-percent oxygen.

(4) **Elevate the lower extremities -** Since blood flow to the heart and brain may have been diminished, circulation can be improved by raising the legs slightly. It is not recommended that the entire body be tilted, since the abdominal organs pressing against the diaphragm may interfere with respiration. **Exceptions to the rule of raising the feet are cases of head and chest injuries**, when it is desirable to lower the pressure in the injured parts; in these cases, the upper part of the body should be elevated slightly. Whenever there is any doubt as to the best position, lay the patient flat.

(5) **Avoid rough handling -** Handle the patient as little and as gently as possible. Body motion has a tendency to aggravate shock conditions.

(6) **Prevent loss of body heat -** Keep the patient warm but guard against overheating, which can aggravate shock. Remember to place a blanket under as well as on top of the patient, to prevent loss of heat into the ground, boat, or ship deck.

(7) **Keep the patient lying down -** A prone position avoids taxing the circulatory system. However, some patients, such as those with heart disorders, will have to be transported in a semi-sitting position.

(8) Give nothing by mouth.

APPENDIX N

OPERATING AND EMERGENCY PROCEDURES

N-1 INTRODUCTION

Operating Procedures and Emergency Procedures are key items in the safe operation of a DLSS. Written procedures covering normal and emergency operations are required for the following purposes:

- To ensure that the normal operation of the diving system is within the safe operating conditions for which certification is granted

- To ensure that there are adequate corrective procedures to cope with emergencies

- To ensure that sufficient operating stations are identified and that the duties of operating personnel are adequately defined

N-2 APPROVAL PROCESS

All Operating Procedures (OPs) and Emergency Procedures (EPs) shall be approved in writing by the NAVSEA or NAVFAC code responsible for providing technical direction of the system. The System Certification Authority (SCA) shall require that this approval is granted prior to system certification. Compliance with approved OPs and EPs is required to sustain system certification. Any changes to these procedures must have the approval of the NAVSEA OR NAVFAC code responsible for technical direction and the concurrence of the SCA.

The adequacy of the normal and emergency procedures formulated by the sponsor for operation of the diving system shall be demonstrated. In cases where a procedure cannot be performed in a satisfactory manner, the sponsor must prepare an acceptable procedure for accomplishing the desired objective.

In accordance with the *U.S. Navy Diving and Manned Hyperbaric Systems Safety Certification Manual*, SS521-AA-MAN-010, review and approval of all OPs/EPs by NAVSEA 00C3 for afloat or portable DLSS or by NAVFAC 04B for fixed, shorebased facilities is required prior to scheduling an on-site certification survey. Submission of OPs/EPs for approval must precede the requested on-site survey date by 90 calendar days to allow complete review and resolution of questions. The following procedures apply:

- The command shall validate the OPs/EPs as complete and correct in the forwarding letter. The address for NAVSEA is: Commander, Naval Sea Systems Command, Supervisor of Diving (Code 00C3), Arlington, VA. The address for NAVFAC is: Commander, Naval Facility Engineering Command (Code 04B), 200 Stovall St., Alexandria, VA 22332.

- Drawing accuracy must be verified by the command because drawings are used as a guide for evaluating OPs/EPs. Fully verified system schematics/drawings with components, gas consoles, manifolds and valves clearly labeled should be forwarded with the OPs/EPs.

- Approved OPs/EPs shall not be changed without written NAVSEA/NAVFAC approval.

- The command shall retain system documentation pertaining to DLSS approval, i.e., PSOBs, supporting manufacturing documentation, and OPs/EPs.

The format for OPs/EPs is as follows:

- System: (Name or description, consistent with drawings)

- Item, Component, Description, Procedure, Location, Check, Note (Read in seven columns)

Example

- System:High Pressure Air

- Item/Component/Description/Procedure /Location /Check/Note

1. ALP-15/Reducer outlet/Open /Salvage Hold/

2. ALP-GA-7/Reducer outlet/Observe /Salvage Hold/Note 1

The Check column will be initialed by the operator executing the procedure. The Note column identifies hazards or items of particular concern.

Telephone numbers for additional information are:

NAVSEA (703) 607-2766

NAVFAC (703) 325-0044

APPENDIX O

U. S. NAVY CIVILIAN DIVING

O-1 INTRODUCTION

U.S. Navy Civilian Divers are governed by the provisions of the U.S. Navy Diving Program, yet they must also comply with U.S. Government Occupational Health and Safety Administration (OSHA) diving standards, delineated in 29 CFR Part 910 Subpart T; Subj: Commercial Diving Operations. U.S. Navy Civilian Divers are identified as all permanent Navy employees who have been formally trained at an approved U.S. Navy diving school as either a SCUBA diver, Second Class diver or First Class diver. Commercial divers contracted by the Navy and not permanent government employees are not subject to these provisions.

Most directives of the U.S. Navy Diving Program provide parallel requirements, or are similar enough not to be considered of substantive difference. Several requirements of OSHA do, however, exceed those delineated for U.S. Navy divers and must be identified to insure compliance by USN Civilian Divers to both standards. Therefore, the following restrictions, in addition to all other requirements addressed in this manual, apply to USN Civilian Divers:

- **SCUBA Diving (Air)**
  1. SCUBA diving will not be conducted:
     a. To depths deeper than 130 fsw
     b. To depths deeper than 100 fsw unless a recompression chamber is on site
  2. All SCUBA cylinder manifolds will be equipped with a manual reserve (J valve), or an independent reserve cylinder with a separate regulator must be carried.
- **Surface-Supplied Air Diving**
  1. Surface-Supplied air diving will not be conducted to depths greater than 190 fsw
  2. Dives will be limited to inwater decompression times of less than 120 minutes
  3. A stage will be required for MK 12 dives
  4. An emergency gas supply (come home bottle) is required for any dive for which direct access to the surface is not available
  5. Installed system depth gauges must be calibrated within six months
- **Mixed-Gas Diving**
  1. All Mixed-gas diving will be limited to:
     a. A maximum depth of 220 fsw
     b. Less than 120 minutes total inwater decompression time
     c. Having a recompression chamber on site
- **Recompression Chamber**
  1. A recompression chamber will be on site for all planned decompression dives or dives deeper than 100 fsw
  2. Civilian divers will remain at the location of a manned recompression chamber for one hour after surfacing from a dive which requires a recompression chamber on site