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REVISION 5

U.S. Navy Diving Manual

Volume 1:	Diving Principles and Policies
Volume 2:	Air Diving Operations
Volume 3:	Mixed Gas Surface Supplied Diving Operations
Volume 4:	Closed-Circuit and Semiclosed Circuit Diving Operations
Volume 5:	Diving Medicine and Recompression Chamber Operations

SUPERSEDES NAVSEA 0994-LP-001-9010, REVISION 4, Dated 20 January 1999, Which Shall Be Destroyed in Accordance With Applicable Security Regulations.

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CERTIFICATION STATEMENT

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Foreword

Department of the Navy
Naval Sea Systems Command
30 Nov 2005

Revision 5 of the U.S. Navy Diving Manual is a comprehensive update and includes the latest procedures and equipment currently being used by military working divers. You must review this manual in its entirety.

This revision formally incorporates the Operational Risk Management (ORM) process into Navy dive planning. Though we work in an extremely hazardous and unforgiving environment, Navy diving's excellent safety record is founded in a strong tradition of careful operational planning and thoughtful risk assessment and management. Live to dive again by remembering established principles embodied in our maxim: “Plan your dive and dive your plan.”

The Dive Manual cannot cover every possible contingency that will be faced in the field by the Diving Supervisor running the side. Therefore, confidently rely on your training, this manual and proven ORM principles and procedures to guide you in making decisions and in taking actions in order to protect your divers while completing your mission; be eternally vigilant.

I would like to thank LCDR Paul Fleischman, who managed the colossal task of reviewing and revising this manual. He was directly and ably supported by Master Diver Fred Orns, Master Diver Steve Smith and Master Diver Byron Van Horn; their experience-based input was critical. In addition, I appreciate and thank Captain (Dr.) John Murray and Captain (Dr.) Dave Southerland for the multiple hours of effort they invested in this review. Finally, I must recognize and thank retired Captain (Dr.) Ed Flynn for his enlightened contribution and thorough technical review.

This new revision is also reformatted for electronic dissemination and in addition, will be promulgated on a CD-ROM. Changes to the manual will be posted on the NAVSEA 00C web site (www.supsalv.org) to ensure accurate and timely updates.

Comments and recommendations to the U.S. Navy Diving Manual may be forwarded to Supervisor of Diving, Naval Sea Systems Command, 1333 Isaac Hull Ave. SE, Washington Navy Yard, DC 20376-1073 or call commercial 202-781-5200, DSN 326-5200.

M. T. HELMKAMP
Supervisor of Diving

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PROLOGUE

Department of the Navy
Naval Sea Systems Command
December 2005

Our first “Manual For Divers” written in 1905 was superseded in 1916 by the legendary Gunner Stillson’s greatly improved “US Navy Diving Manual.” Though these compilations of waterfront savvy, hard-fought experience, and diving trial and error were based more on blood, sweat and tears than scientific knowledge, they nonetheless paved the way for safe and efficient exploration of the depths of the sea.

US Navy Divers now work safely in depths that Gunner Stillson and his dive team could only dream about. And the US Navy Diving Program expanded beyond early “hard-hat” diving to include mixed-gas deep-sea diving, and open, closed and semi-closed circuit rigs and ultimately saturation diving to reach continental shelf depths. The scope of technical work accomplished by Navy Divers is as unbounded as their ingenuity and perseverance under pressure.

One hundred years later, Gunner Stillson’s heart and soul are still contained in this latest revision to the US Navy Diving Manual. Though much larger in scope (and number of pages!), and benefiting from a century of scientific discovery, it remains calibrated by that same waterfront savvy and deck-plate experience, and is the principal operational and technical guide of the US Navy Diving Program.

“On the bottom: Red Diver – Go to work!”

J. R. WILKINS III
US Navy Supervisor of Salvage & Diving
Director of Ocean Engineering

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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 that 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 Never do a forceful Valsalva maneuver during descent. A forceful Valsalva maneuver can result in alternobaric vertigo or barotrauma to the inner ear. (Page 3-25)

WARNING 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. (Page 3-25)

WARNING Reducing the oxygen partial pressure does not instantaneously reverse the biochemical changes in the central nervous system caused by high oxygen partial pressures. 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 2 or 3 minutes. (Page 3-45)

WARNING CPR should not be initiated on a severely hypothermic diver unless it can be determined that the heart has stopped or is in ventricular fibrillation. CPR should not be initiated in a patient that is breathing. (Page 3-55)

WARNING Do not use a malfunctioning compressor to pump diver's breathing air or charge diver's air storage flasks as this may result in contamination of the diver's air supply. (Page 4-11)

WARNING Welding or cutting torches may cause an explosion on penetration of gas-filled compartments, resulting in serious injury or death. (Page 6-22)

WARNING SCUBA equipment is not authorized for use in enclosed space diving. (Page 6-27)

WARNING These are the minimum personnel levels required. ORM may require these personnel levels be increased so the diving operations can be conducted safely. (Page 6-31)

WARNING Skip-breathing may lead to hypercapnia and shall not be practiced. (Page 7-30)

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 7-36)

WARNING During enclosed space diving, all divers shall be outfitted with a MK 21 MOD 1, MK 20 MOD 0, or EXO BR MS that includes a diver-to-diver and diver-to-topside communications system and an EGS for the diver inside the space. (Page 8-30)

WARNING For submarine ballast tanks, 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 Chapter 4, or the submarine L.P. blower, and tests confirm that the atmosphere is safe for breathing. Tests of the air in the enclosed space shall be conducted hourly. Testing shall be done in accordance with NSTM 074, Volume 3, Gas Free Engineering (S9086-CH-STM-030/CH-074) for forces afloat, and NAVSEA S-6470-AA-SAF-010 for shore-based facilities. If the divers smell any unusual odors they shall immediately don their EGS. (Page 8-30)

WARNING **If the diving equipment should fail, the diver shall immediately switch to the EGS and abort the dive. (Page 8-30)**

WARNING **If job conditions call for using a steel cable or a chain as a descent line, the Diving Officer must approve such use. (Page 8-33)**

WARNING **Table 9-4 cannot be used with constant ppO_2 diving equipment, such as the MK 16. (Page 9-42)**

WARNING **Altitudes above 10,000 feet can impose serious stress on the body resulting in significant medical problems while the acclimatization process takes place. Ascents to these altitudes must be slow to allow acclimatization to occur and prophylactic drugs may be required. These exposures should always be planned in consultation with a Diving Medical Officer. Commands conducting diving operations above 10,000 feet may obtain the appropriate decompression procedures from NAVSEA 00C. (Page 9-44)**

WARNING **The interval from leaving 40 fsw in the water to arriving at 50 fsw in the chamber cannot exceed 5 minutes. (Page 14-7)**

WARNING **Failure to adhere to these guidelines could result in serious injury or death. (Page 17-17)**

WARNING **No repetitive dives are authorized after an emergency procedure requiring a shift to the EBS. (Page 17-21)**

WARNING **Hypoxia and hypercapnia may give the diver little or no warning prior to onset of unconsciousness. (Page 17-31)**

WARNING **Failure to adhere to these guidelines could result in serious injury or death. (Page 18-14)**

WARNING **Hypoxia and hypercapnia may give the diver little or no warning prior to onset of unconsciousness. (Page 18-24)**

WARNING **CPR should not be initiated on a severely hypothermic diver unless it can be determined that the heart has stopped or is in ventricular fibrillation. CPR should not be initiated in a patient that is breathing. (Page 19-15)**

WARNING The MK 25 does not have a carbon dioxide-monitoring capability. Failure to adhere to canister duration operations planning could lead to unconsciousness and/or death. (Page 19-18)

WARNING Drug therapy should be administered only after consultation with a Diving Medical Officer by qualified inside tenders adequately trained and capable of administering prescribed medications. (Page 20-31).

WARNING The gag valve must remain open at all times. Close only if relief valve fails. (Page 21-19)

WARNING This procedure is to be performed with an unmanned chamber to avoid exposing occupants to unnecessary risks. (Page 21-20)

WARNING Fire/Explosion Hazard. No matches, lighters, electrical appliances, or flammable materials permitted in chamber. (Page 21-29)

CAUTION When in doubt, always recompress. (Page 3-29)

CAUTION Do not institute active rewarming with severe cases of hypothermia. (Page 3-55)

CAUTION Prior to use of VVDS as a buoyancy compensator, divers must be thoroughly familiar with its use. (Page 7-9)

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 8-29)

CAUTION Never attempt to interpolate between decompression schedules. (Page 9-6)

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 11-6)

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 11-6)

CAUTION The MK 16 MOD 0 UBA provides no visual warning of excess CO_2 problems. The diver should be aware of CO_2 toxicity symptoms. (Page 17-5)

CAUTION There is an increased risk of oxygen toxicity in diving the MK 16 MOD 1 over the MK 16 Mod 0 especially during the descent phase of deep

(greater than 200 fsw) HeO_2 dives. Diving supervisors and divers should be aware that oxygen partial pressures of 1.6 or higher may be temporarily experienced due to a ppO_2 overshoot. Refer to paragraph 18-10.1.1 for information on recognizing and preventing CNS O_2 Toxicity. (Page 18-13)

CAUTION **Do not institute active rewarming with severe cases of hypothermia. (Page 19-15)**

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. (Page 20-3)**

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 and new tender to the surface in the outer lock, while maintaining the original tender at depth. (Page 20-4)**

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U.S. NAVY DIVING MANUAL

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CHAPTER 1
History of Diving

1-1 INTRODUCTION

1-1.1 **Purpose.** This chapter provides a general history of the development of military diving operations.

1-1.2 **Scope.** This chapter outlines the hard work and dedication of a number of individuals who were pioneers in the development of diving technology. As with any endeavor, it is important to build on the discoveries of our predecessors and not repeat mistakes of the past.

1-1.3 **Role of the U.S. Navy.** The U.S. Navy is a leader 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. Navy diving is no longer 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 inspecting and repairing naval vessels to minimize downtime and the need for dry-docking. Other aspects of fleet diving include recovering practice and research torpedoes, installing and repairing underwater electronic arrays, underwater construction, and locating and recovering downed aircraft.

1-2 SURFACE-SUPPLIED AIR DIVING

The origins of diving are firmly rooted in man's need and desire to engage in maritime commerce, to conduct salvage and military operations, and to expand the frontiers of knowledge through exploration, research, and development.

Diving, as a profession, can be traced back more than 5,000 years. Early divers confined their efforts to waters less than 100 feet deep, performing salvage work and harvesting food, sponges, coral, and mother-of-pearl. A Greek historian, Herodotus, recorded 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. Alexander the Great 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.

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 payment scale 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 3 feet, only a one-tenth share.

1-2.1 **Breathing Tubes.** The most obvious and crucial step to broadening a diver's capabilities was providing an air supply that would permit him to stay underwater. Hollow reeds or tubes extending to the surface allowed a diver to remain submerged for an extended period, but he could accomplish little in the way of useful work. Breathing tubes were employed in military operations, permitting an undetected approach to an enemy stronghold (Figure 1-1).

At first glance, it seemed logical that a longer breathing tube was the only requirement for extending a diver's range. In fact, a number of early designs used leather hoods with long flexible tubes supported at the surface by floats. There is no record, however, that any of these devices were actually constructed or tested. The result may well have been the drowning of the diver. At a depth of 3 feet, it is nearly 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. Successful diving operations require that the pressure be overcome or eliminated. Throughout history, imaginative devices were designed to overcome this problem, 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 1-1. 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.

Figure 1-2. Assyrian Frieze (900 B.C.).

1-2.2 **Breathing Bags.** An entire series of designs was based on the idea of a breathing bag carried by the diver. An Assyrian frieze of the ninth century B.C. shows what appear to be divers using inflated animal skins as air tanks. However, these men were probably swimmers using skins for flotation. It would be impossible to submerge while holding such an accessory (Figure 1-2).

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."

1-2.3 **Diving Bells.** Between 1500 and 1800 the diving bell was developed, enabling divers to remain underwater for hours rather than minutes. The diving bell is a bell-shaped apparatus with the bottom open to the sea.

The first diving bells were large, strong tubs weighted to sink in a vertical position, trapping enough air to permit a diver to breathe for several hours. Later diving bells were suspended by a cable from the surface. They had no significant underwater maneuverability beyond that provided by moving the support ship. The diver could remain in the bell if positioned directly over his work, or could venture outside for short periods of time by holding his breath.

The first reference to an actual practical diving bell was made in 1531. For several hundred years thereafter, rudimentary but effective bells were used with regularity. In the 1680s, 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 1-3). In an early demonstration of his system, he and four companions remained at 60 feet in the Thames River for almost 1½ hours. Nearly 26 years later, Halley spent more than 4 hours at 66 feet using an improved version of his bell.

1-2.4 **Diving Dress Designs.** With an increasing number of military and civilian wrecks littering the shores of Great Britain each year, there was strong incentive to develop a diving dress that would increase the efficiency of salvage operations.

1-2.4.1 **Lethbridge's Diving Dress.** In 1715, Englishman John Lethbridge developed a one-man, completely enclosed diving dress (Figure 1-4). The Lethbridge equipment was 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 quite successful with his invention and participated in salvaging 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 10 fathoms (60 feet),

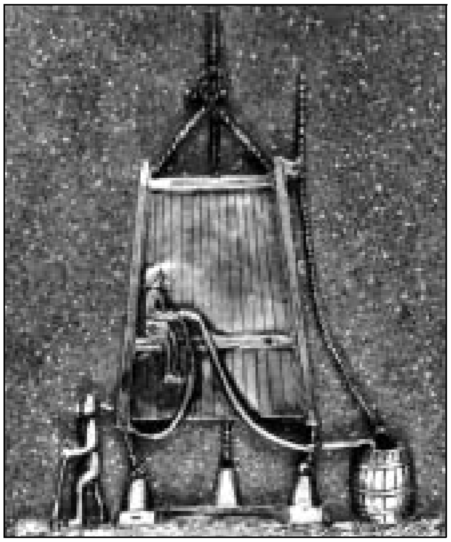

Figure 1-3. Engraving of Halley's Diving Bell.

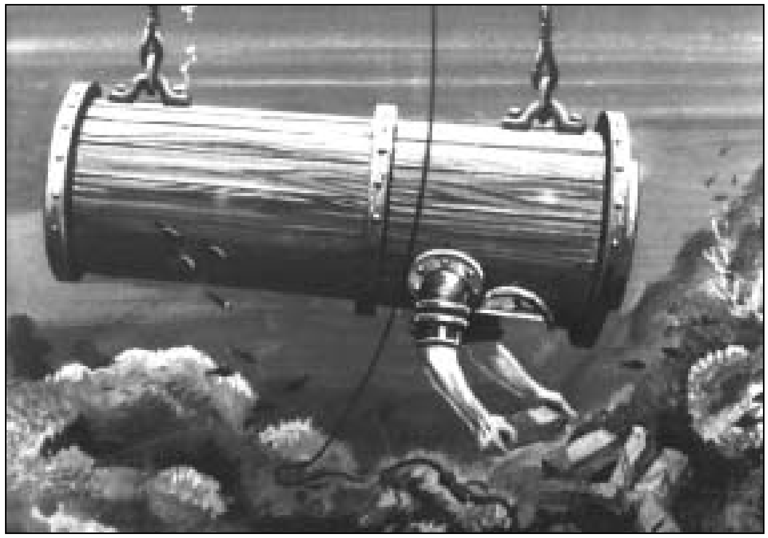

Figure 1-4. Lethbridge's Diving Suit.

with about 12 fathoms the maximum, and that he could remain underwater for 34 minutes.

Several designs similar to Lethbridge's were used in succeeding years. However, all had 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 19th century when a hand-operated pump capable of delivering air under pressure was developed.

1-2.4.2 **Deane's Patented Diving Dress.** Several men produced a successful apparatus at the same time. In 1823, two salvage operators, John and Charles Deane, patented the basic design for a smoke apparatus that permitted firemen to move about in burning buildings. By 1828, the apparatus evolved into Deane's 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 rested on the diver's shoulders, held in place by its own weight and straps to a waist belt. Exhausted or surplus air passed out from under the edge of the helmet and posed no problem as long as the diver was upright. If he fell, however, the helmet could quickly fill with water. In 1836, the Deanes issued a diver's manual, perhaps the first ever produced.

1-2.4.3 **Siebe's Improved Diving Dress.** Credit for developing the first practical diving dress has been given to Augustus Siebe. Siebe's initial contribution to diving was 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 (Figure 1-5). Known as Siebe's Improved Diving Dress, this apparatus is the direct ancestor of the MK V standard deep-sea diving dress.

1-2.4.4 **Salvage of the HMS *Royal George*.** By 1840, several types of diving dress were being used in actual diving operations. At that time, a unit of the British Royal Engineers was engaged in removing the remains of the sunken warship, HMS *Royal George*. The warship was fouling a major fleet anchorage just outside Portsmouth, England. 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. Wary of the Deane apparatus because of the possibility of helmet flooding, he formally recommended that the Siebe dress be adopted for future operations.

Figure 1-5. Siebe's First Enclosed Diving Dress and Helmet.

When Pasley's project was 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 6 or 7 hours a day, much of it spent at depths of 60 to 70 feet. Pasley and his men did not realize the implications of the observation. What appeared to be rheumatism was instead a symptom of a far more serious physiological problem that, within a few years, was to become of great importance to the diving profession.

1-2.5 **Caissons.** At the same time that a practical diving dress was being perfected, inventors were working to improve the diving bell by increasing its size and adding high-capacity air pumps that could deliver enough pressure to keep water entirely out of the bell's interior. The improved pumps 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 for projects such as excavating bridge footings or constructing tunnel sections where long periods of work were required. These dry chambers were known as *caissons*, a French word meaning "big boxes" (Figure 1-6).

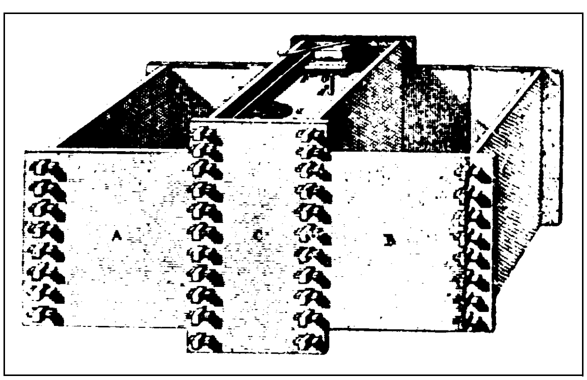

Figure 1-6. French Caisson. This caisson could be floated over the work site and lowered to the bottom by flooding the side tanks.

Caissons were designed to provide ready access from the surface. By using an air lock, the pressure inside could be maintained while men or materials could be passed in and out. The caisson was a major step in engineering technology and its use grew quickly.

1-2.6 Physiological Discoveries.

1-2.6.1 **Caisson Disease (Decompression Sickness).** With the increasing use of caissons, a new and unexplained malady began to affect the caisson workers. Upon returning to the surface at the end of a shift, the divers frequently would be struck by dizzy spells, breathing difficulties, or sharp pains in the joints or abdomen. The sufferer usually recovered, but might never be completely free of some of the symptoms. Caisson workers often noted that they felt better working on the job, but wrongly attributed this to being more rested at the beginning of a shift.

As caisson work extended to 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—the "bends."

Today the bends is the most well-known danger of diving. Although men had been diving for thousands of years, few men had spent much time working under great atmospheric pressure until the time of the caisson. 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.

1-2.6.1.1 ***Cause of Decompression Sickness.*** The actual cause of caisson disease was first clinically described in 1878 by a French physiologist, Paul Bert. In studying 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 it was 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. Gas bubbles formed throughout the body, causing the wide range of symptoms associated with the disease. Paralysis or death could occur if the flow of blood to a vital organ was blocked by the bubbles.

1-2.6.1.2 ***Prevention and Treatment of Decompression Sickness.*** 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 by returning to the pressure of the caisson as soon as the symptom appeared.

Within a few years, specially designed recompression chambers were being placed at job sites to provide a more controlled situation for handling the bends. 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 subway tunnel under the Hudson River between New

York and New Jersey. The recompression chamber markedly reduced the number of serious cases and fatalities caused by the bends.

Bert's recommendation that divers ascend gradually and steadily was not a complete success, however; some divers continued to suffer from the bends. The general thought at the time was 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 and diver inefficiency beyond that depth. Occasionally, divers would lose consciousness while working at 120 feet.

1-2.6.2 **Inadequate Ventilation.** J.S. Haldane, an English physiologist, conducted experiments with Royal Navy divers from 1905 to 1907. He determined that part of the problem was due to the divers not adequately ventilating their helmets, causing high levels of carbon dioxide to accumulate. To solve the problem, he established a standard supply rate of flow (1.5 cubic feet of air per minute, measured at the pressure of the diver). Pumps capable of maintaining the flow and ventilating the helmet on a continuous basis were used.

Haldane also composed a set of diving tables that established a method of decompression in stages. Though restudied and improved over the years, these tables remain the basis of the accepted method for bringing a diver to the surface.

As a result of Haldane's studies, the practical operating depth for air divers was extended to slightly more than 200 feet. The limit was not imposed by physiological factors, but by the capabilities of the hand-pumps available to provide the air supply.

1-2.6.3 **Nitrogen Narcosis.** Divers soon were moving into deeper water and another unexplained malady began to appear. The diver would appear intoxicated, sometimes feeling euphoric and frequently losing judgment to the point of forgetting the dive's purpose. In the 1930s this "rapture of the deep" was linked to nitrogen in the air breathed under higher pressures. Known as nitrogen narcosis, this condition occurred 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 were developed for deep diving (see section 1-4, Mixed-Gas Diving).

Figure 1-7. Armored Diving Suit.

1-2.7 **Armored Diving Suits.** Numerous inventors, many with little or no underwater experience, worked to create an armored diving suit that would free the diver from pressure problems (Figure 1-7). In an armored suit, the diver could breathe air at normal atmospheric pressure and descend to great depths without any ill effects. The barrel diving suit, designed by John Lethbridge in 1715, had been an armored suit in essence, but one with a limited operating depth.

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 feet, but was never reached in actual diving. More recent pursuits in the area of armored suits, now called one-atmosphere diving suits, have demonstrated their capability for specialized underwater tasks to 2,000 feet of saltwater (fsw).

1-2.8 **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. This 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 if the air supply were interrupted. 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 interfering 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 operated by an interior push button. The regulating valve allowed some control of the atmospheric pressure. A supplementary relief valve, known as the spitcock, was added to the left side of the helmet. A safety catch was also incorporated to keep the helmet attached to the breast plate. The exhaust valve and the communications system were improved by 1927, and the weight of the helmet was decreased to be more comfortable for the diver.

After 1927, the MK V 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-1920s. With its associated deep-sea dress and umbilical, the MK V was used for all submarine rescue and salvage work undertaken in peacetime and practically all salvage work undertaken during World War II. The MK V Diving Helmet was the standard U.S. Navy diving equipment until succeeded by the MK 12 Surface-Supplied Diving System (SSDS) in February 1980 (see Figure 1-8). The MK 12 was replaced by the MK 21 in December 1993.

1-3 SCUBA DIVING

The diving equipment developed by Charles and John Deane, Augustus Siebe, and other inventors gave man the ability to remain and work underwater for extended periods, but movement was greatly limited by the requirement for surface-supplied air. Inventors searched for methods to increase the diver's movement

Figure 1-8. MK 12 and MK V.

without increasing the hazards. The best solution was to provide the diver with a portable, self-contained air supply. For many years the self-contained underwater breathing apparatus (SCUBA) was only a theoretical possibility. Early attempts to supply self-contained compressed air to divers were not successful due to the limitations of air pumps and containers to compress and store air at sufficiently high pressure. SCUBA development took place gradually, however, evolving into three basic types:

- Open-circuit SCUBA (where the exhaust is vented directly to the surrounding water),
- Closed-circuit SCUBA (where the oxygen is filtered and recirculated), and
- Semiclosed-circuit SCUBA (which combines features of the open- and closed-circuit types).

1-3.1 **Open-Circuit SCUBA.** In the open-circuit apparatus, air is inhaled from a supply cylinder and the exhaust is vented directly to the surrounding water.

1-3.1.1 **Rouquayrol's Demand Regulator.** The first and highly necessary component of an open-circuit apparatus was a demand regulator. Designed early in 1866 and patented by Benoist Rouquayrol, the regulator adjusted the flow of air from the tank to meet the diver's breathing and pressure requirements. However, because cylinders strong enough 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.

1-3.1.2 **LePrieur's Open-Circuit SCUBA Design.** The thread of open-circuit development was picked up in 1933. Commander LePrieur, a French naval officer, 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. The lack of a demand regulator, coupled with extremely short endurance, severely limited the practical use of LePrieur's apparatus.

1-3.1.3 **Cousteau and Gagnan's Aqua-Lung.** At the same time that actual combat operations were being carried out with closed-circuit apparatus, two Frenchmen 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, Jacques-Yves Cousteau and Emile Gagnan combined an improved demand regulator with high-pressure air tanks to create the first truly efficient and safe open-circuit SCUBA, known as the Aqua-Lung. 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.

The Aqua-Lung was the culmination of hundreds of years of progress, blending the work of Rouquayol, LePrieur, and Fleuss, a pioneer in closed-circuit SCUBA development. Cousteau used his gear successfully to 180 fsw without significant difficulty and with the end of the war the Aqua-Lung quickly became a commercial success. Today the Aqua-Lung is the most widely used diving equipment, opening the underwater world to anyone with suitable training and the fundamental physical abilities.

1-3.1.4 **Impact of SCUBA on Diving.** The underwater freedom brought about by the development of SCUBA led to a rapid growth of interest in diving. Sport diving has become very popular, 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 has grown around commercial diving, with the major portion of activity in offshore petroleum production.

After World War II, the art and science of diving progressed rapidly, with emphasis placed on improving existing diving techniques, creating new methods, and developing the equipment required 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.

1-3.2 Closed-Circuit SCUBA. The basic closed-circuit system, or oxygen rebreather, uses a cylinder of 100 percent oxygen that supplies a breathing bag. The oxygen used by the diver is recirculated in the apparatus, passing through a chemical filter that removes carbon dioxide. Oxygen is added from the tank to replace that consumed in breathing. For special warfare operations, the closed-circuit system has a major advantage over the open-circuit type: it does not produce a telltale trail of bubbles on the surface.

1-3.2.1 **Fleuss' Closed-Circuit SCUBA.** Henry A. Fleuss developed the first commercially practical closed-circuit SCUBA between 1876 and 1878 (Figure 1-9). The

Fleuss device consisted of a watertight rubber face mask and a breathing bag connected to a copper tank of 100 percent oxygen charged to 450 psi. By using oxygen instead of compressed air as the breathing medium, Fleuss eliminated the need for high-strength tanks. In early models of this apparatus, the diver controlled the makeup feed of fresh oxygen with a hand valve.

Fleuss successfully tested his apparatus in 1879. In the first test, he remained in a tank of water for about an hour. In the second test, he walked along a creek bed at a depth of 18 feet. During the second test, Fleuss turned off his oxygen feed to see what would happen. He was soon unconscious, and suffered gas embolism as his tenders pulled him to the surface. A few weeks after his recovery, Fleuss made arrangements to put his recirculating design into commercial production.

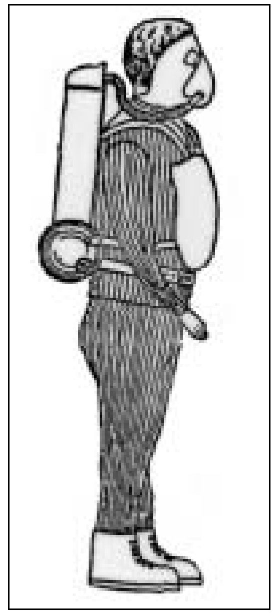

Figure 1-9. Fleuss Apparatus.

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

1-3.2.2 **Modern Closed-Circuit Systems.** As development of the closed-circuit design continued, the Fleuss equipment was improved by adding 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 World War II, closed-circuit units were widely used for combat diving operations (see paragraph 1-3.5.2).

Some modern closed-circuit systems employ 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.

1-3.3 **Hazards of Using Oxygen in SCUBA.** Fleuss had been unaware of the serious problem of oxygen toxicity caused by breathing 100 percent oxygen under pressure. Oxygen toxicity apparently was not encountered when he used his apparatus in early shallow water experiments. The danger of oxygen poisoning had actually been discovered prior to 1878 by Paul Bert, the physiologist who first proposed controlled decompression as a way to avoid the bends. In laboratory experiments with animals, Bert demonstrated that breathing oxygen under pressure could lead to convulsions and death (central nervous system oxygen toxicity).

In 1899, J. Lorrain Smith found that breathing oxygen over prolonged periods of time, even at pressures not sufficient to cause convulsions, could lead to pulmonary oxygen toxicity, a serious lung irritation. The results of these experiments, however, were not widely publicized. For many years, working divers were unaware of the dangers of oxygen poisoning.

The true seriousness of the problem was not apparent until large numbers of combat swimmers were being trained in the early years of World War II. After a number of oxygen toxicity accidents, the British established an operational depth limit of 33 fsw. Additional research on oxygen toxicity continued in the U.S. Navy after the war and resulted in the setting of a normal working limit of 25 fsw for 75 minutes for the Emerson oxygen rebreather. A maximum emergency depth/time limit of 40 fsw for 10 minutes was also allowed.

These limits eventually proved operationally restrictive, and prompted the Navy Experimental Diving Unit to reexamine the entire problem of oxygen toxicity in the mid-1980s. As a result of this work, more liberal and flexible limits were adopted for U.S. Navy use.

1-3.4 Semiclosed-Circuit SCUBA. The semiclosed-circuit SCUBA combines features of the open and closed-circuit 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; an equal amount of the recirculating mixed-gas stream is continually exhausted to the water. Because the quantity of makeup gas is constant regardless of depth, the semiclosed-circuit SCUBA provides significantly greater endurance than open-circuit systems in deep diving.

1-3.4.1 **Lambertsen's Mixed-Gas Rebreather.** In the late 1940s, Dr. C.J. Lambertsen proposed that mixtures of nitrogen or helium with an elevated oxygen content be used in SCUBA to expand the depth range beyond that allowed by 100-percent oxygen rebreathers, while simultaneously minimizing the requirement for decompression.

In the early 1950s, Lambertsen introduced the FLATUS I, a semiclosed-circuit SCUBA that continually added a small volume of mixed gas, rather than pure oxygen, to a rebreathing circuit. The small volume of new gas provided the oxygen necessary for metabolic consumption while exhaled carbon dioxide was absorbed in an absorbent canister. Because inert gas, as well as oxygen, was added to the rig, and because the inert gas was not consumed by the diver, a small amount of gas mixture was continuously exhausted from the rig.

1-3.4.2 **MK 6 UBA.** In 1964, after significant development work, the Navy adopted a semiclosed-circuit, mixed-gas rebreather, the MK 6 UBA, for combat swimming and EOD operations. Decompression procedures for both nitrogen-oxygen and helium-oxygen mixtures were developed at the Navy Experimental Diving Unit. The apparatus had a maximum depth capability of 200 fsw and a maximum endurance of 3 hours depending on water temperature and diver activity. Because the apparatus was based on a constant mass flow of mixed gas, the endurance was independent of the diver's depth.

In the late 1960s, work began on a new type of mixed-gas rebreather technology, which was later used in the MK 15 and MK 16 UBAs. In this UBA, the oxygen partial pressure was controlled at a constant value by an oxygen sensing and addition system. As the diver consumed oxygen, an oxygen sensor detected the fall in oxygen partial pressure and signaled an oxygen valve to open, allowing a small amount of pure oxygen to be admitted to the breathing circuit from a cylinder. Oxygen addition was thus exactly matched to metabolic consumption. Exhaled carbon dioxide was absorbed in an absorption canister. The system had the endurance and completely closed-circuit characteristics of an oxygen rebreather without the concerns and limitations associated with oxygen toxicity.

Beginning in 1979, the MK 6 semiclosed-circuit underwater breathing apparatus (UBA) was phased out by the MK 15 closed-circuit, constant oxygen partial pressure UBA. The Navy Experimental Diving Unit developed decompression procedures for the MK 15 with nitrogen and helium in the early 1980s. In 1985, an improved low magnetic signature version of the MK 15, the MK 16, was approved for Explosive Ordnance Disposal (EOD) team use.

1-3.5 **SCUBA Use During World War II.** Although closed-circuit equipment was restricted to shallow-water use and carried with it the potential danger of oxygen toxicity, its design had reached a suitably high level of efficiency by World War II. During the war, combat swimmer breathing units were widely used by navies on both sides of the conflict. The swimmers used various modes of underwater attack. Many notable successes were achieved including the sinking of several battleships, cruisers, and merchant ships.

1-3.5.1 **Diver-Guided Torpedoes.** Italian divers, using closed-circuit gear, rode chariot torpedoes fitted with seats and manual controls in repeated attacks against British ships. In 1936, the Italian Navy tested a chariot torpedo system in which the divers used a descendant of the Fleuss SCUBA. This was the Davis Lung (Figure 1-10). It was originally designed as a submarine escape device and was later manufactured in Italy under a license from the English patent holders.

Figure 1-10. Original Davis Submerged Escape Apparatus.

British divers, carried to the scene of action in midget submarines, aided in placing explosive charges under the keel of the German battleship *Tirpitz*. The British began their chariot program in 1942 using the Davis Lung and exposure suits. Swimmers using the MK 1 chariot dress quickly discovered that the steel oxygen bottles adversely affected the compass of the chariot torpedo. Aluminum oxygen cylinders were not readily available in England, but German aircraft used aluminum oxygen cylinders that were almost the same size as the steel cylinders aboard the chariot torpedo. Enough aluminum cylinders were salvaged from downed enemy bombers to supply the British forces.

Changes introduced in the MK 2 and MK 3 diving dress involved improvements in valving, faceplate design, and arrangement of components. After the war, the MK 3 became the standard Royal Navy shallow water diving dress. The MK 4 dress was used near the end of the war. Unlike the MK 3, the MK 4 could be supplied with oxygen from a self-contained bottle or from a larger cylinder carried in the chariot. This gave the swimmer greater endurance, yet preserved freedom of movement independent of the chariot torpedo.

In the final stages of the war, the Japanese employed an underwater equivalent of their kamikaze aerial attack—the kaiten diver-guided torpedo.

1-3.5.2 **U.S. Combat Swimming.** There were two groups of U.S. combat swimmers during World War II: Naval beach reconnaissance swimmers and U.S. operational swimmers. Naval beach reconnaissance units did not normally use any breathing devices, although several models existed.

U.S. operational swimmers, however, under the Office of Strategic Services, developed and applied advanced methods for true self-contained diver-submersible operations. They employed the Lambertsen Amphibious Respiratory Unit (LARU), a rebreather invented by Dr. C.J. Lambertsen (see Figure 1-11). The LARU was a closed-circuit oxygen UBA used in special warfare operations where a complete absence of exhaust bubbles was required. Following World War II, the Emerson-Lambertsen Oxygen Rebreather replaced the LARU (Figure 1-12). The Emerson Unit was used extensively by Navy special warfare divers until 1982, when it was replaced by the Draeger Lung Automatic Regenerator (LAR) V. The LAR V is the standard unit now used by U.S. Navy combat swimmers (see Figure 1-13).

Figure 1-11. Lambertsen Amphibious Respiratory Unit (LARU)

Today Navy combat swimmers are organized into two separate groups, each with specialized training and missions. The Explosive Ordnance Disposal (EOD) team handles, defuses, and disposes of munitions and other explosives. The Sea, Air and Land (SEAL) special warfare teams make up the second group of Navy

Figure 1-12. Emerson-Lambertsen Oxygen Rebreather.

Figure 1-13. Draeger LAR V UBA.

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 counter-insurgency and guerrilla warfare operations. The SEALs also participated in the space program by securing flotation collars to returned space capsules and assisting astronauts during the helicopter pickup.

1-3.5.3 **Underwater Demolition.** The Navy's Underwater Demolition Teams (UDTs) 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 was a daylight reconnaissance and demolition project off the beaches of Saipan in June 1944. In March of 1945, preparing for the invasion of Okinawa, one underwater demolition team achieved the exceptional record of removing 1,200 underwater obstacles in 2 days, under heavy fire, without a single casualty.

Because suitable equipment was not readily available, diving apparatus was not extensively used by the UDT during the war. UDT experimented with a modified Momsen lung and other types of breathing apparatus, but not until 1947 did the Navy's acquisition 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. The UDTs have since been incorporated into the Navy Seal Teams.

1-4 MIXED-GAS DIVING

Mixed-gas diving operations are conducted using a breathing medium other than air. This medium may consist of:

- Nitrogen and oxygen in proportions other than those found in the atmosphere
- A mixture of other inert gases, such as helium, with oxygen.

The breathing medium can also be 100 percent oxygen, which is not a mixed gas, but which requires training for safe use. Air may be used in some phases of a mixed-gas dive.

Mixed-gas diving is a complex undertaking. A mixed-gas diving operation requires extensive special training, detailed planning, specialized and advanced equipment and, in many applications, requires extensive surface-support personnel and facilities. Because mixed-gas operations are often conducted at great depth or for extended periods of time, hazards to personnel increase greatly. Divers studying mixed-gas diving must first be qualified in air diving operations.

In recent years, to match basic operational requirements and capabilities, the U.S. Navy has divided mixed-gas diving into two categories:

- Nonsaturation diving without a pressurized bell to a maximum depth of 300 fsw, and

- Saturation diving for dives of 150 fsw and greater depth or for extended bottom time missions.

The 300-foot limit is based primarily on the increased risk of decompression sickness when nonsaturation diving techniques are used deeper than 300 fsw.

1-4.1 Nonsaturation Diving.

1-4.1.1 **Helium-Oxygen (HeO_2) Diving.** An inventor named Elihu Thomson theorized that helium might be an appropriate substitute for the nitrogen in a diver's breathing supply. He estimated that at least a 50-percent gain in working depth could be achieved by substituting helium for nitrogen. In 1919, he suggested that the U.S. Bureau of Mines investigate this possibility. Thomson directed his suggestion to the Bureau of Mines rather than the Navy Department, since the Bureau of Mines held a virtual world monopoly on helium marketing and distribution.

1-4.1.1.1 ***Experiments with Helium-Oxygen Mixtures.*** In 1924, the Navy and the Bureau of Mines jointly sponsored a series of experiments using helium-oxygen mixtures. The preliminary work was conducted at the Bureau of Mines Experimental Station in Pittsburgh, Pennsylvania. Figure 1-14 is a picture of an early Navy helium-oxygen diving manifold.

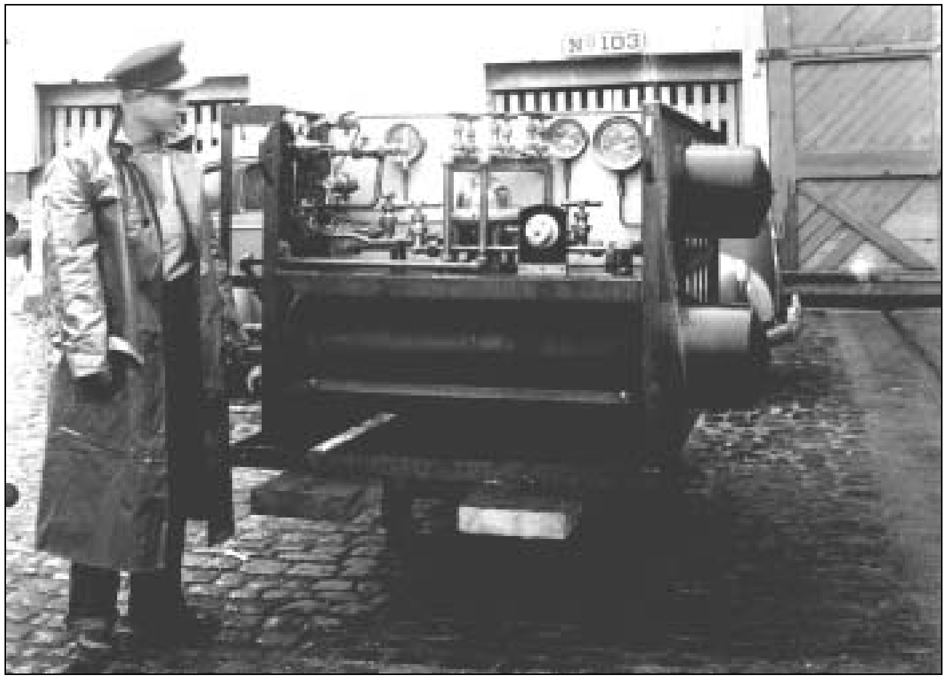

Figure 1-14. Helium-Oxygen Diving Manifold.

The first experiments showed no detrimental effects on test animals or humans from breathing a helium-oxygen mixture, and decompression time was shortened. The principal physiological effects noted by divers using helium-oxygen were:

- Increased sensation of cold caused by the high thermal conductivity of helium
- The high-pitched distortion or "Donald Duck" effect on human speech that resulted from the acoustic properties and reduced density of the gas

These experiments clearly showed that helium-oxygen mixtures offered great advantages over air for deep dives. They laid the foundation for developing the reliable decompression tables and specialized apparatus, which are the cornerstones of modern deep diving technology.

In 1937, at the Experimental Diving Unit research facility, a diver wearing a deep-sea diving dress with a helium-oxygen breathing supply was compressed in a chamber to a simulated depth of 500 feet. The diver was not told the depth and when asked to make an estimate of the depth, the diver reported that it felt as if he were at 100 feet. During decompression at the 300-foot mark, the breathing mixture was switched to air and the diver was troubled immediately by nitrogen narcosis.

The first practical test of helium-oxygen came in 1939, when the submarine USS *Squalus* was salvaged from a depth of 243 fsw. In that year, the Navy issued decompression tables for surface-supplied helium-oxygen diving.

1-4.1.1.2 ***MK V MOD 1 Helmet.*** Because helium was expensive and shipboard supplies were limited, the standard MK V MOD 0 open-circuit helmet was not economical for surface-supplied helium-oxygen diving. After experimenting with several different designs, the U.S. Navy adopted the semiclosed-circuit MK V MOD 1 (Figure 1-15).

Figure 1-15. MK V MOD 1 Helmet.

The MK V MOD 1 helmet was equipped with a carbon dioxide absorption canister and venturi-powered recirculator assembly. Gas in the helmet was continuously recirculated through the carbon dioxide scrubber assembly by the venturi. By removing carbon dioxide by scrubbing rather than ventilating the helmet, the fresh gas flow into the helmet was reduced to the amount required to replenish oxygen. The gas consumption of the semiclosed-circuit MK V MOD 1 was approximately 10 percent of that of the open-circuit MK V MOD 0.

The MK V MOD 1, with breastplate and recirculating gas canister, weighed approximately 103 pounds compared to 56 pounds for the standard air helmet and breastplate. It was fitted with a lifting ring at the top of the helmet to aid in hatting the diver and to keep the weight off his shoulders until he was lowered into the water. The diver was lowered into and raised out of the water by a diving stage connected to an onboard boom.

1-4.1.1.3 ***Civilian Designers.*** U.S. Navy divers were not alone in working with mixed gases or helium. In 1937, civilian engineer Max Gene Nohl reached 420 feet in Lake Michigan while breathing helium-oxygen and using a suit of his own design. In 1946, civilian diver Jack Browne, designer of the lightweight diving mask that bears his name, made a simulated helium-oxygen dive of 550 feet. In 1948, a British Navy diver set an open-sea record of 540 fsw while using war-surplus helium provided by the U.S.

1-4.1.2 **Hydrogen-Oxygen Diving.** In countries where the availability of helium was more restricted, divers experimented with mixtures of other gases. The most notable example is that of the Swedish engineer Arne Zetterstrom, who worked with hydrogen-oxygen mixtures. The explosive nature of such mixtures was well known, but it was also known that hydrogen would not explode when used in a mixture of less than 4 percent oxygen. At the surface, this percentage of oxygen would not be sufficient to sustain life; at 100 feet, however, the oxygen partial pressure would be the equivalent of 16 percent oxygen at the surface.

Zetterstrom devised a simple method for making the transition from air to hydrogen-oxygen without exceeding the 4-percent oxygen limit. At the 100-foot level, he replaced his breathing air with a mixture of 96 percent nitrogen and 4 percent oxygen. He then replaced that mixture with hydrogen-oxygen in the same proportions. In 1945, after some successful test dives to 363 feet, Zetterstrom reached 528 feet. Unfortunately, as a result of a misunderstanding on the part of his topside support personnel, he was brought to the surface too rapidly. Zetterstrom did not have time to enrich his breathing mixture or to adequately decompress and died as a result of the effects of his ascent.

1-4.1.3 **Modern Surface-Supplied Mixed-Gas Diving.** The U.S. Navy and the Royal Navy continued to develop procedures and equipment for surface-supplied helium-oxygen diving in the years following World War II. In 1946, the Admiralty Experimental Diving Unit was established and, in 1956, during open-sea tests of helium-oxygen diving, a Royal Navy diver reached a depth of 600 fsw. Both navies conducted helium-oxygen decompression trials in an attempt to develop better procedures.

In the early 1960s, a young diving enthusiast from Switzerland, Hannes Keller, proposed techniques to attain great depths while minimizing decompression requirements. Using a series of gas mixtures containing varying concentrations of oxygen, helium, nitrogen, and argon, Keller demonstrated the value of elevated oxygen pressures and gas sequencing in a series of successful dives in mountain lakes. In 1962, with partial support from the U.S. Navy, he reached an open-sea depth of more than 1,000 fsw off the California coast. Unfortunately, this dive was marred by tragedy. Through a mishap unrelated to the technique itself, Keller lost consciousness on the bottom and, in the subsequent emergency decompression, Keller’s companion died of decompression sickness.

By the late 1960s, it was clear that surface-supplied diving deeper than 300 fsw was better carried out using a deep diving (bell) system where the gas sequencing techniques pioneered by Hannes Keller could be exploited to full advantage, while maintaining the diver in a state of comfort and security. The U.S. Navy developed decompression procedures for bell diving systems in the late 1960s and early 1970s. For surface-supplied diving in the 0-300 fsw range, attention was turned to developing new equipment to replace the cumbersome MK V MOD 1 helmet.

1-4.1.4 **MK 1 MOD 0 Diving Outfit.** The new equipment development proceeded along two parallel paths, developing open-circuit demand breathing systems suitable for deep helium-oxygen diving, and developing an improved recirculating helmet to replace the MK V MOD 1. By the late 1960s, engineering improvements in demand regulators had reduced breathing resistance on deep dives to acceptable levels. Masks and helmets incorporating the new regulators became commercially available. In 1976, the U.S. Navy approved the MK 1 MOD 0 Lightweight, Mixed-Gas Diving Outfit for dives to 300 fsw on helium-oxygen (Figure 1-16). The MK 1 MOD 0 Diving Outfit incorporated a full face mask (bandmask) featuring a demand open-circuit breathing regulator and a backpack for an emergency gas supply. Surface contact was maintained through an umbilical that included the breathing gas hose, communications cable, lifeline strength member and pneumofathometer hose. The diver was dressed in a dry suit or hot water suit depending on water temperature. The equipment was issued as a lightweight diving outfit in a system with sufficient equipment to support a diving operation employing two working divers and a standby diver. The outfit was used in conjunction with an open diving bell that replaced the traditional diver's stage and added additional safety. In 1990, the MK 1 MOD 0 was replaced by the MK 21 MOD 1 (Superlite 17 B/NS) demand helmet. This is the lightweight rig in use today.

Figure 1-16. MK 1 MOD 0 Diving Outfit

In 1985, after an extensive development period, the direct replacement for the MK V MOD 1 helmet was approved for Fleet use. The new MK 12 Mixed-Gas Surface-Supplied Diving System (SSDS) was similar to the MK 12 Air SSDS, with the addition of a backpack assembly to allow operation in a semiclosed-circuit mode. The MK 12 system was retired in 1992 after the introduction of the MK 21 MOD 1 demand helmet.

1-4.2 **Diving Bells.** Although open, pressure-balanced diving bells have been used for several centuries, it was not until 1928 that a bell appeared that was capable of maintaining internal pressure when raised to the surface. In that year, Sir Robert H. Davis, the British pioneer in diving equipment, designed the Submersible Decompression Chamber (SDC). The vessel was conceived to reduce the time a diver had to remain in the water during a lengthy decompression.

The Davis SDC was a steel cylinder capable of holding two men, with two inward-opening hatches, one on the top and one on the bottom. A surface-supplied diver was deployed over the side in the normal mode and the bell was lowered to a depth of 60 fsw with the lower hatch open and a tender inside. Surface-supplied air ventilated the bell and prevented flooding. The diver's deep decompression stops were taken in the water and he was assisted into the bell by the tender upon arrival at 60 fsw. The diver's gas supply hose and communications cable were removed from the helmet and passed out of the bell. The lower door was closed and the bell was lifted to the deck where the diver and tender were decompressed within the safety and comfort of the bell.

By 1931, the increased decompression times associated with deep diving and the need for diver comfort resulted in the design of an improved bell system. Davis designed a three-compartment deck decompression chamber (DDC) to which the SDC could be mechanically mated, permitting the transfer of the diver under pressure. The DDC provided additional space, a bunk, food and clothing for the diver's comfort during a lengthy decompression. This procedure also freed the SDC for use by another diving team for continuous diving operations.

The SDC-DDC concept was a major advance in diving safety, but was not applied to American diving technology until the advent of saturation diving. In 1962, E. A. Link employed a cylindrical, aluminum SDC in conducting his first open-sea saturation diving experiment. In his experiments, Link used the SDC to transport the diver to and from the sea floor and a DDC for improved diver comfort. American diving had entered the era of the Deep Diving System (DDS) and advances and applications of the concept grew at a phenomenal rate in both military and commercial diving.

1-4.3 **Saturation Diving.** As divers dove deeper and attempted more ambitious underwater tasks, a safe method to extend actual working time at depth became crucial. Examples of saturation missions include submarine rescue and salvage, sea bed implantments, construction, and scientific testing and observation. These types of operations are characterized by the need for extensive bottom time and, consequently, are more efficiently conducted using saturation techniques.

1-4.3.1 **Advantages of Saturation Diving.** In deep diving operations, decompression is the most time-consuming factor. For example, a diver working for an hour at 200 fsw would be required to spend an additional 3 hours and 20 minutes in the water undergoing the necessary decompression.

However, once a diver becomes saturated with the gases that make decompression necessary, the diver does not need additional decompression. When the 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 could remain under pressure for the entire period of the required task, the diver would face a lengthy decompression only when completing the project. For a 40-hour task at 200 fsw, a saturated diver would spend 5 days at bottom pressure and 2 days in decompression, as opposed to spending 40 days making 1-hour dives with long decompression periods using conventional methods.

The U.S. Navy developed and proved saturation diving techniques in its Sealab series. Advanced saturation diving techniques are being developed in ongoing programs of research and development at the Navy Experimental Diving Unit (NEDU), Navy Submarine Medical Research Laboratory (NSMRL), and many institutional and commercial hyperbaric facilities. In addition, saturation diving using Deep Diving Systems (DDS) is now a proven capability.

1-4.3.2 **Bond's Saturation Theory.** True scientific impetus was first given to the saturation concept in 1957 when a Navy diving medical officer, Captain George F. Bond, theorized that the tissues of the body would eventually become saturated with inert gas if exposure time was long enough. Bond, then a commander and the director of the Submarine Medical Center at New London, Connecticut, met with Captain Jacques-Yves Cousteau and determined that the data required to prove the theory of saturation diving could be developed at the Medical Center.

1-4.3.3 **Genesis Project.** With the support of the U.S. Navy, Bond initiated the Genesis Project to test the theory of saturation diving. A series of experiments, first with test animals and then with humans, proved that once a diver was saturated, further extension of bottom time would require no additional decompression time. Project Genesis proved that men could be sustained for long periods under pressure, and what was then needed was a means to put this concept to use on the ocean floor.

1-4.3.4 **Developmental Testing.** Several test dives were conducted in the early 1960s:

- The first practical open-sea demonstrations of saturation diving were undertaken in September 1962 by Edward A. Link and Captain Jacques-Yves Cousteau.
- Link's Man-in-the-Sea program had one man breathing helium-oxygen at 200 fsw for 24 hours in a specially designed diving system.
- 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.
- Cousteau's Conshelf One supported six men breathing nitrogen-oxygen at 35 fsw for 7 days.
- In 1964, Link and Lambertsen conducted a 2-day exposure of two men at 430 fsw.
- Cousteau's Conshelf Two experiment maintained a group of seven men for 30 days at 36 fsw and 90 fsw with excursion dives to 330 fsw.

1-4.3.5 **Sealab Program.** The best known U.S. Navy experimental effort in saturation diving was the Sealab program.

1-4.3.5.1 ***Sealabs I and II.*** After completing the Genesis Project, the Office of Naval Research, the Navy Mine Defense Laboratory and Bond's small staff of volunteers gathered in Panama City, Florida, where construction and testing of the Sealab I habitat began in December 1963.

In 1964, Sealab I placed four men underwater for 10 days at an average depth of 192 fsw. The habitat was eventually raised to 81 fsw, where the divers were transferred to a decompression chamber that was hoisted aboard a four-legged offshore support structure.

In 1965, Sealab II put three teams of ten men each in a habitat at 205 fsw. Each team spent 15 days at depth and one man, Astronaut Scott Carpenter, remained for 30 days (see Figure 1-17).

1-4.3.5.2 ***Sealab III.*** The follow-on seafloor experiment, Sealab III, was planned for 600 fsw. This huge undertaking required not only extensive development and testing of equipment but also assessment of human tolerance to high-pressure environments.

To prepare for Sealab III, 28 helium-oxygen saturation dives were performed at the Navy Experimental Diving Unit to depths of 825 fsw between 1965 and 1968. In 1968, a record-breaking excursion dive to 1,025 fsw from a saturation depth of 825 fsw was performed at the Navy Experimental Diving Unit (NEDU). The culmination of this series of dives was a 1,000 fsw, 3-day saturation dive conducted jointly by the U.S. Navy and Duke University in the hyperbaric chambers at Duke. This was the first time man had been saturated at 1,000 fsw. The Sealab III preparation experiments showed that men could readily perform useful work at pressures up to 31 atmospheres and could be returned to normal pressure without harm.

Figure 1-17. Sealab II.

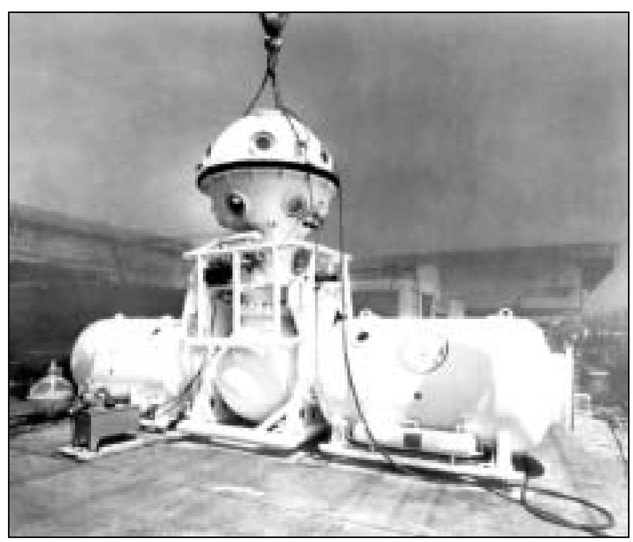

Figure 1-18. U.S. Navy's First DDS, SDS-450.

Reaching the depth intended for the Sealab III habitat required highly specialized support, including a diving bell to transfer divers under pressure from the habitat to a pressurized deck decompression chamber. The experiment, however, was marred by tragedy. Shortly after being compressed to 600 fsw in February 1969, Aquanaut Berry Cannon convulsed and drowned. This unfortunate accident ended the Navy's involvement with seafloor habitats.

1-4.3.5.3 ***Continuing Research.*** Research and development continues to extend the depth limit for saturation diving and to improve the diver's capability. The deepest dive attained by the U.S. Navy to date was in 1979 when divers from the NEDU completed a 37-day, 1,800 fsw dive in its Ocean Simulation Facility. The world record depth for experimental saturation, attained at Duke University in 1981, is 2,250 fsw, and non-Navy open sea dives have been completed to in excess of 2300 fsw. Experiments with mixtures of hydrogen, helium, and oxygen have begun and the success of this mixture was demonstrated in 1988 in an open-sea dive to 1,650 fsw.

Advanced saturation diving techniques are being developed in ongoing programs of research and development at NEDU, Navy Submarine Medical Research Laboratory (NSMRL), and many institutional and commercial hyperbaric facilities. In addition, saturation diving using Deep Diving Systems (DDS) is now a proven capability.

1-4.4 Deep Diving Systems (DDS). Experiments in saturation technique required substantial surface support as well as extensive underwater equipment. DDS are a substantial improvement over previous methods of accomplishing deep undersea work. The DDS is readily adaptable to saturation techniques and safely maintains the saturated diver under pressure in a dry environment. Whether employed for saturation or nonsaturation diving, the Deep Diving System totally eliminates long decompression periods in the water where the diver is subjected to extended environmental stress. The diver only remains in the sea for the time spent on a given task. 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 Deep Diving System consists of a Deck Decompression Chamber (DDC) mounted on a surface-support ship. A Personnel Transfer Capsule (PTC) is mated to the DDC, and the combination is pressurized to a storage depth. Two or more divers enter the PTC, which 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 divers swim out to accomplish their work. The divers 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. Upon completing the task, the divers enters the capsule, close the hatch and return to the support ship with the interior of the PTC still at the working pressure. The capsule is hoisted aboard and mated to the pressurized DDC. The divers enter the larger, more comfortable DDC via an entry lock. They remain in the DDC until they must return to the undersea job site. Decompression is carried out comfortably and safely on the support ship.

The Navy developed four deep diving systems: ADS-IV, MK 1 MOD 0, MK 2 MOD 0, and MK 2 MOD 1.

1-4.4.1 **ADS-IV.** Several years prior to the Sealab I experiment, the Navy successfully deployed the Advanced Diving System IV (ADS-IV) (see Figure 1-18). The ADS-IV was a small deep diving system with a depth capability of 450 fsw. The ADS-IV was later called the SDS-450.

1-4.4.2 **MK 1 MOD 0.** The MK 1 MOD 0 DDS was a small system intended to be used on the new ATS-1 class salvage ships, and underwent operational evaluation in 1970. The DDS consisted of a Personnel Transfer Capsule (PTC) (see Figure 1-19), a life-support system, main control console and two deck decompression chambers to handle two teams of two divers each. This system was also used to operationally evaluate the MK 11 UBA, a semiclosed-circuit mixed-gas apparatus, for saturation diving. The MK 1 MOD 0 DDS conducted an open-sea dive to 1,148 fsw in 1975. The MK 1 DDS was not installed on the ATS ships as originally planned, but placed on a barge and assigned to Harbor Clearance Unit Two. The system went out of service in 1977.

Figure 1-19. DDS MK 1 Personnel Transfer Capsule.

Figure 1-20. PTC Handling System, *Elk River*.

1-4.4.3 **MK 2 MOD 0.** The Sealab III experiment required a much larger and more capable deep diving system than the MK 1 MOD 0. The MK 2 MOD 0 was constructed and installed on the support ship *Elk River* (IX-501). With this system, divers could be saturated in the deck chamber under close observation and then transported to the habitat for the stay at depth, or could cycle back and forth between the deck chamber and the seafloor while working on the exterior of the habitat.

The bell could also be used in a non-pressurized observation mode. The divers would be transported from the habitat to the deck decompression chamber, where final decompression could take place under close observation.

1-4.4.4 **MK 2 MOD 1.** Experience gained with the MK 2 MOD 0 DDS on board *Elk River* (IX-501) (see Figure 1-20) led to the development of the MK 2 MOD 1, a larger, more sophisticated DDS. The MK 2 MOD 1 DDS supported two four-man teams for long term saturation diving with a normal depth capability of 850 fsw. The diving complex consisted of two complete systems, one at starboard and one at port. Each system had a DDC with a life-support system, a PTC, a main control console, a strength-power-communications cable (SPCC) and ship support. The two systems shared a helium-recovery system. The MK 2 MOD 1 was installed on the ASR 21 Class submarine rescue vessels.

1-5 SUBMARINE SALVAGE AND RESCUE

At the beginning of the 20th century, all major navies turned their attention toward developing a weapon of immense potential—the military submarine. The highly effective use of the submarine 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 to 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 improve Navy diving equipment. Throughout a 3-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.

1-5.1 **USS F-4.** The experience gained in Stillson's program was put to dramatic use in 1915 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 using lifting pontoons. What was most remarkable, however, was that the divers completed a major salvage effort working at the extreme depth of 304 fsw, using air as a breathing mixture. The decompression requirements limited bottom time for each dive to about 10 minutes. Even for such a limited time, nitrogen narcosis made it difficult for the divers to concentrate on their work.

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 U.S. entered World War I, the staff and graduates of the school were sent to Europe, where they conducted various salvage operations along the coast of France.

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.

1-5.2 **USS S-51.** In September of 1925, the USS S-51 submarine was rammed by a passenger liner and sunk in 132 fsw off Block Island, Rhode Island. Public pressure to raise the submarine and recover the bodies of the crew was intense. Navy diving was put in sharp focus, realizing 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 10-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. 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.

Losing 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 occurred.

1-5.3 **USS S-4.** 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 that bears his name. It was given its first operational test in 1929 when 26 officers and men successfully surfaced from an intentionally bottomed submarine.

1-5.4 **USS *Squalus*.** 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, was proven in 1939 when the USS *Squalus*, carrying a crew of 50, sank in 243 fsw. 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 (see Figure 1-21). This salvage and rescue operation marked the first operational use of HeO_2 in salvage diving. One of the primary missions of salvage divers was to attach a down-haul cable for the Submarine Rescue Chamber (SRC). Following renovation, the submarine, renamed USS *Sailfish*, compiled a proud record in World War II.

Figure 1-21. Recovery of the *Squalus*.

1-5.5 **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 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.

1-5.6 **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 Navy.

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 diving to 5,000 fsw and rescues to 2,500 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.

1-6 SALVAGE DIVING

1-6.1 World War II Era.

1-6.1.1 **Pearl Harbor.** Navy divers were plunged into the war with the Japanese raid on Pearl Harbor. The raid began at 0755 on 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 worked to recover ammunition from the magazines of sunken ships, to be ready in the event of a second attack.

The immense salvage effort that followed at Pearl Harbor was highly successful. Most of the 101 ships in the harbor at the time of the attack sustained damage. The battleships, one of the primary targets of the raid, were hardest hit. Six battleships were sunk and one was heavily damaged. Four were salvaged and returned to the fleet for combat duty; the former battleships USS *Arizona* and USS *Utah* could not be salvaged. The USS *Oklahoma* was righted and refloated but sank en route to a shipyard in the U.S.

Battleships were not the only ships salvaged. 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 Pearl Harbor effort, Navy divers spent 16,000 hours underwater during 4,000 dives. Contract civilian divers contributed another 4,000 diving hours.

1-6.1.2 **USS *Lafayette*.** 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.

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

1-6.1.3 **Other Diving Missions.** Salvage operations were not 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.

1-6.2 **Vietnam Era.** Harbor Clearance Unit One (HCU 1) was commissioned 1 February 1966 to provide mobile salvage capability in direct support of combat operations in Vietnam. Homeported at Naval Base Subic Bay, Philippines, HCU 1 was dedicated primarily to restoring seaports and rivers to navigable condition following their loss or diminished use through combat action.

Beginning as a small cadre of personnel, HCU 1 quickly grew in size to over 260 personnel, as combat operations in littoral environment intensified. At its peak, the unit consisted of five Harbor Clearance teams of 20 to 22 personnel each and a varied armada of specialized vessels within the Vietnam combat zone.

As their World War II predecessors before them, the salvors of HCU 1 left an impressive legacy of combat salvage accomplishments. HCU 1 salvaged hundreds of small craft, barges, and downed aircraft; refloated many stranded U.S. Military and merchant vessels; cleared obstructed piers, shipping channels, and bridges; and performed numerous underwater repairs to ships operating in the combat zone.

Throughout the colorful history of HCU 1 and her East Coast sister HCU 2, the vital role salvage forces play in littoral combat operations was clearly demonstrated. Mobile Diving and Salvage Unit One and Two, the modern-day descendants of the Vietnam era Harbor Clearance Units, have a proud and distinguished history of combat salvage operations.

1-7 OPEN-SEA DEEP DIVING RECORDS

Diving records have been set and broken with increasing regularity since the early 1900s:

- **1915**. The 300-fsw mark was exceeded. Three U.S. Navy divers, F. Crilley, W.F. Loughman, and F.C. Nielson, reached 304 fsw using the MK V dress.
- **1972**. The MK 2 MOD 0 DDS set the in-water record of 1,010 fsw.
- **1975**. Divers using the MK 1 Deep Dive System descended to 1,148 fsw.
- **1977**. A French dive team broke the open-sea record with 1,643 fsw.

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

- **Present**. Commercial open water diving operations to over 1,000 fsw.

1-8 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. 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 person who prepares for a dive has the opportunity and obligation to take along the knowledge of his or her 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 and a detailed knowledge of his or her own physiology and how it is affected by the environment. Divers must learn to adapt to environmental conditions to successfully carry out their missions.

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

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CHAPTER 2
Underwater Physics

2-1 INTRODUCTION

2-1.1 Purpose. This chapter describes the laws of physics as they affect humans in the water.

2-1.2 Scope. A thorough understanding of the principles outlined in this chapter is essential to safe and effective diving performance.

2-2 PHYSICS

Humans readily function within the narrow atmospheric envelope present at the earth's surface and are seldom concerned with survival requirements. Outside the boundaries of the envelope, the environment is hostile and our existence depends on our ability to counteract threatening forces. To function safely, divers must understand the characteristics of the subsea environment and the techniques that can be used to modify its effects. To accomplish this, a diver must have a basic knowledge of physics—the science of matter and energy. Of particular importance to a diver are the behavior of gases, the principles of buoyancy, and the properties of heat, light, and sound.

2-3 MATTER

Matter is anything that occupies space and has mass, and is the building block of the physical world. Energy is required to cause matter to change course or speed. The diver, the diver's air supply, everything that supports him or her, and the surrounding environment is composed of matter.

2-3.1 Elements. An *element* is the simplest form of matter that exhibits distinct physical and chemical properties. An element cannot be broken down by chemical means into other, more basic forms. Scientists have identified more than 100 elements in the physical universe. Elements combine to form the more than four million substances known to man.

2-3.2 Atoms. The *atom* is the smallest particle of matter that carries the specific properties of an element. Atoms are made up of electrically charged particles known as protons, neutrons, and electrons. Protons have a positive charge, neutrons have a neutral charge, and electrons have a negative charge.Molecules

2-3.3 Molecules. *Molecules* are formed when atoms group together (Figure 2-1). 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. 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

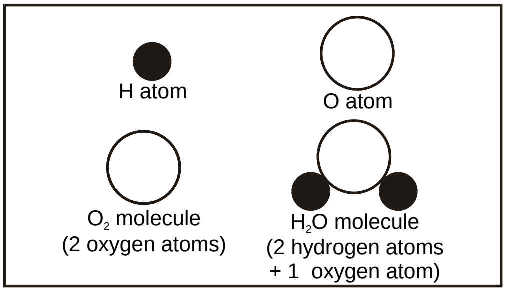

Figure 2-1. Molecules. Two similar atoms combine to form an oxygen molecule while the atoms of two different elements, hydrogen and oxygen, combine to form a water molecule.

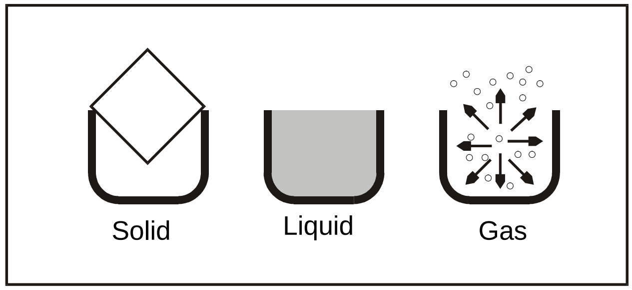

Figure 2-2. The Three States of Matter.

breathing mixtures is important when calculating a diver's decompression obligations.

2-3.4 **The Three States of Matter.** Matter can exist in one of three natural states: solid, liquid, or gas (Figure 2-2). A solid has a definite size and shape. A liquid has a definite volume, but takes the shape of the container. Gas has neither definite shape nor volume, but will expand to fill a container. Gases and liquids are collectively referred to as fluids.

The physical state of a substance depends primarily upon temperature and partially upon pressure. A solid is the coolest of the three states, with its molecules rigidly aligned in fixed patterns. The molecules move, but their motion is like a constant vibration. As heat is added the molecules increase their motion, slip apart from each other and move around; the solid becomes a liquid. A few of the molecules will spontaneously leave the surface of the liquid and become a gas. When the substance reaches its boiling point, the molecules are moving very rapidly in all directions and the liquid is quickly transformed into a gas. Lowering the temperature reverses the sequence. As the gas molecules cool, their motion is reduced and the gas condenses into a liquid. As the temperature continues to fall, the liquid reaches the freezing point and transforms to a solid state.

2-4 MEASUREMENT

Physics relies heavily upon standards of comparison of one state of matter or energy to another. To apply the principles of physics, divers must be able to employ a variety of units of measurement.

2-4.1 **Measurement Systems.** Two systems of measurement are widely used throughout the world. Although the English System is commonly used in the United States, the most common system of measurement in the world is the International System of Units. The International System of Units, or *SI* system, is a modernized metric system designated in 1960 by the General Conference on Weights and Measures. The SI system is decimal based with all its units related, so that it is not necessary to use calculations to change from one unit to another. The

SI 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. Because measurements are often reported in units of the English system, it is important to be able to convert them to SI units. Measurements can be converted from one system to another by using the conversion factors in Table 2-10 through 2-18.

2-4.2 Temperature Measurements. While the English System of weights and measures uses the Fahrenheit (°F) temperature scale, the Celsius (°C) scale is the one most commonly used in scientific work. Both scales are based upon the freezing and boiling points of water. The freezing point of water is 32°F or 0°C; the boiling point of water is 212°F or 100°C. Temperature conversion formulas and charts are found in Table 2-18.

Absolute temperature values are used when employing the ideal gas laws. The absolute temperature scales are based upon absolute zero. Absolute zero is the lowest temperature that could possibly be reached at which all molecular motion would cease (Figure 2-3).

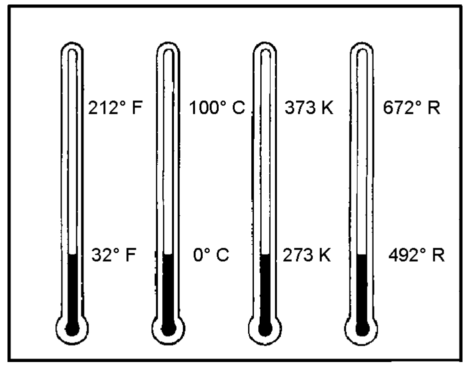

Figure 2-3. Temperature Scales. Fahrenheit, Celsius, Kelvin, and Rankine temperature scales showing the freezing and boiling points of water.

2-4.2.1 **Kelvin Scale.** One example of an absolute temperature scale is the Kelvin scale, which has the same size degrees as the Celsius scale. The freezing point of water is 273°K and boiling point of water is 373°K. Use this formula to convert from Celsius to absolute temperature (Kelvin):

Kelvin (K) = °C + 273

2-4.2.2 **Rankine Scale.** The Rankine scale is another absolute temperature scale, which has the same size degrees as the Fahrenheit scale. The freezing point of water is 492°R and the boiling point of water is 672°R. Use this formula to convert from Fahrenheit to absolute temperature (degrees Rankine, °R):

°R = °F + 460

2-4.3 Gas Measurements. When measuring gas, actual cubic feet (acf) of a gas refers to the quantity of a gas at ambient conditions. The most common unit of measurement for gas in the United States is standard cubic feet (scf). Standard cubic feet relates the quantity measurement of a gas under pressure to a specific condition. The specific condition is a common basis for comparison. For air, the standard cubic foot is measured at 60°F and 14.696 psia.

2-5 ENERGY

Energy is the capacity to do work. The six basic types of energy are mechanical, heat, light, chemical, electromagnetic, and nuclear, and may appear in a variety of forms (Figure 2-4). Energy is a vast and complex aspect of physics beyond the scope of this manual. Consequently, this chapter only covers a few aspects of light, heat, and mechanical energy because of their unusual effects underwater and their impact on diving.

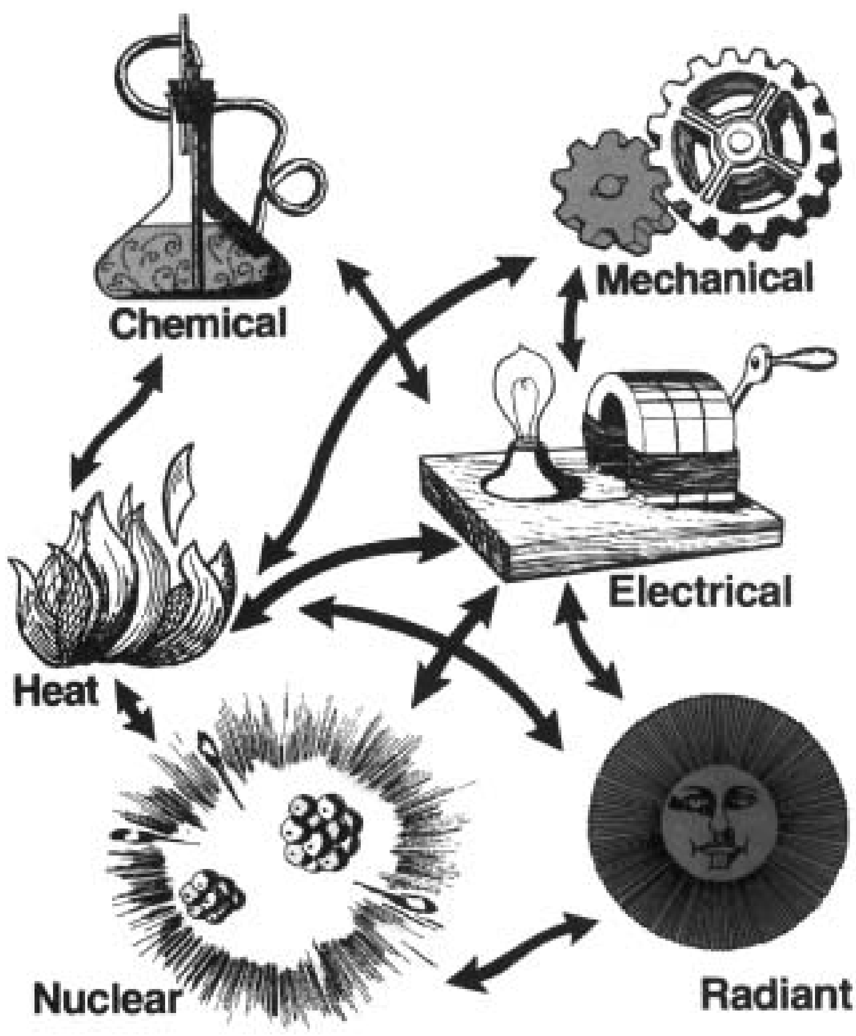

Figure 2-4. The Six Forms of Energy.

2-5.1 **Conservation of Energy.** The Law of the Conservation of Energy, formulated in the 1840s, states that energy in the universe can neither be created nor destroyed. Energy can be changed, however, from one form to another.

2-5.2 **Classifications of Energy.** The two general classifications of energy are potential energy and kinetic energy. Potential energy is due to position. An automobile parked on a hill with its brakes set possesses potential energy. Kinetic energy is energy of motion. An automobile rolling on a flat road possesses kinetic energy while it is moving.

2-6 LIGHT ENERGY IN DIVING

Refraction, turbidity of the water, salinity, and pollution all contribute to the distance, size, shape, and color perception of underwater objects. Divers must understand the factors affecting underwater visual perception, and must realize that distance perception is very likely to be inaccurate.

2-6.1 **Refraction.** Light passing from an object bends as it passes through the diver's faceplate and the air in his mask (Figure 2-5). This phenomenon is called refraction, and occurs because light travels faster in air than in water. Although the refraction that occurs between the water and the air in the diver's face mask produces undesirable perceptual inaccuracies, air is essential for vision. When a diver loses his face mask, his eyes are immersed in water, which has about the same refractive index as the eye. Consequently, the light is not focused normally and the diver's vision is reduced to a level that would be classified as legally blind on the surface.

Figure 2-5. Objects Underwater Appear Closer.

Refraction can make objects appear closer than they really are. A distant object will appear to be approximately three-quarters of its actual distance. At greater distances, the effects of refraction may be reversed, making objects appear farther away than they actually are. Reduced brightness and contrast combine with refraction to affect visual distance relationships.

Refraction can also affect perception of size and shape. Generally, underwater objects appear to be about 30 percent larger than they actually are. Refraction effects are greater for objects off to the side in the field of view. This distortion interferes with hand-eye coordination, and explains why grasping objects underwater is sometimes difficult for a diver. Experience and training can help a diver learn to compensate for the misinterpretation of size, distance, and shape caused by refraction.

2-6.2 **Turbidity of Water.** Water turbidity can also profoundly influence underwater vision and distance perception. 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 3 or 4 feet may be overestimated; in moderately turbid water, the change might occur at 20 to 25 feet and in very clear water, objects as far away as 50 to 70 feet might appear closer than they actually are. Generally speaking, the closer the object, the more it will appear to be too close, and the more turbid the water, the greater the tendency to see it as too far away.

2-6.3 **Diffusion.** Light scattering 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. The 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.

2-6.4 **Color Visibility.** Object size and distance are not the only characteristics distorted underwater. A variety of factors may combine to alter a diver's color perception. Painting objects different colors is an obvious means of changing their visibility by enhancing their contrast with the surroundings, or by camouflaging them to merge with the background. Determining the most and least visible colors is much more complicated underwater than in air.

Colors are filtered out of light as it enters the 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. Water depth is not the only factor affecting the filtering of colors. Salinity, turbidity, size of the particles suspended in the water, and pollution all affect the color-filtering properties of water. Color 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.

The components of any underwater scene, such as weeds, rocks, and encrusting animals, generally appear to be the same color as the depth or viewing range increases. Objects become distinguishable only by differences in brightness and not color. Contrast becomes the most important factor in visibility; even very large objects may be undetectable if their brightness is similar to that of the background.

2-7 MECHANICAL ENERGY IN DIVING

Mechanical energy mostly affects divers in the form of sound. Sound is a periodic motion or pressure change transmitted through a gas, a liquid, or a solid. Because liquid is denser 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.

2-7.1 **Water Temperature and Sound.** In any body of water, 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, the sound energy transmitted between them decreases. This means that a sound heard 50 meters from its source within one layer may be inaudible a few meters from its source if the diver is in another layer.

2-7.2 **Water Depth and Sound.** In shallow water or in enclosed spaces, reflections and reverberations from the air/water and object/water interfaces produce anomalies in the sound field, such as echoes, dead spots, and sound nodes. When swimming in shallow water, among coral heads, or in enclosed spaces, a diver can expect periodic losses in acoustic communication signals and disruption of acoustic navigation beacons. The problem becomes more pronounced as the frequency of the signal increases.

Because sound travels so quickly underwater (4,921 feet per second), human ears cannot detect the difference in time of arrival of a sound at each ear. Consequently, a diver cannot always locate the direction of a sound source. This disadvantage can have serious consequences for a diver or swimmer trying to locate an object or a source of danger, such as a powerboat.

2-7.2.1 **Diver Work and Noise.** 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). When several divers are working in the same area, the noise and bubbles 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.

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.

2-7.2.2 **Pressure Waves.** Sound is transmitted through water as a series of pressure waves. High-intensity sound is transmitted by correspondingly high-intensity pressure waves. A high-pressure wave transmitted from the water surrounding a diver to the open spaces within the body (ears, sinuses, lungs) may increase the pressure within these open spaces, causing injury. Underwater explosions and sonar can create high-intensity sound or pressure waves. Low intensity sonar, such as depth finders and fish finders, do not produce pressure waves intense enough to endanger divers. However, anti-submarine sonar-equipped ships do pulse dangerous, 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 ¼-inch neoprene hood for ear protection. Experiments have shown that such a hood offers adequate protection when the ultrasonic pulses are of 4-millisecond duration, repeated once per second for acoustic source levels up to 100 watts, at head-to-source distances as short as 0.5 feet (Pence and Sparks, 1978).

2-7.3 Underwater Explosions. An underwater explosion creates a series of waves that are transmitted as hydraulic shock waves in the water, and as seismic waves in the seabed. 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; as it travels outward from the source of the explosion, it loses its intensity. Less severe pressure waves closely follow the initial shock wave. Considerable turbulence and movement of the water in the area of the explosion are evident for an extended time after the detonation.

2-7.3.1 **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 create a high-level shock and pressure waves of short duration over a limited area. Low brisance explosives create a less intense shock and pressure waves of long duration over a greater area.

2-7.3.2 **Characteristics of the Seabed.** Aside from the fact that rock or other bottom debris may be propelled through the water or into the air with shallow-placed charges, bottom conditions can affect an explosion’s pressure waves. A soft bottom tends to dampen reflected shock and pressure waves, while a hard, rock bottom may amplify the effect. Rock strata, ridges and other topographical features of the seabed may affect the direction of the shock and pressure waves, and may also produce secondary reflecting waves.

2-7.3.3 **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.

2-7.3.4 **Water Depth.** At great depth, the shock and pressure waves are drawn out by the greater water volume and are thus reduced in intensity. An explosion near the surface is not weakened to the same degree.

2-7.3.5 **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.

2-7.3.6 **Degree of Submersion of the Diver.** A fully submerged diver receives the total effect of the shock and pressure waves passing over the body. A partially submerged diver whose head and upper body are out of the water, may experience a reduced effect of the shock and pressure waves on the lungs, ears, and sinuses. 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. 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.

2-7.3.7 **Estimating Explosion Pressure on a Diver.** There are various formulas for estimating the pressure wave resulting from an explosion of TNT. The equations vary in format and the results illustrate that the technique for estimation is only an approximation. Moreover, these formulas relate to TNT and are not applicable to other types of explosives.

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

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

Where:

P	=	pressure on the diver in pounds per square inch
W	=	weight of the explosive (TNT) in pounds
r	=	range of the diver from the explosion in feet

Sample Problem. Determine the pressure exerted by a 45-pound charge at a distance of 80 feet.

1. Substitute the known values.

$$P = \frac{13,000\sqrt[3]{45}}{80}$$

2. Solve for the pressure exerted.

$$P = \frac{13,000\sqrt[3]{45}}{80}$$

$$= \frac{13,000 \times 3.56}{80}$$

$$= 578.5$$

Round up to 579 psi.

A 45-pound charge exerts a pressure of 579 pounds per square inch at a distance of 80 feet.

2-7.3.8 **Minimizing the Effects of an Explosion.** 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 pounds per square inch. To minimize the effects, the diver can position himself 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.

2-8 HEAT ENERGY IN DIVING

Heat 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.

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.

Heat is generated in many ways. Burning fuels, chemical reactions, friction, and electricity all generate heat. Heat is transmitted from one place to another by conduction, convection, and radiation.

2-8.1 **Conduction, Convection, and Radiation.** *Conduction* is the transmission of heat by direct contact. Because water is an excellent heat conductor, an unprotected diver can lose a great deal of body heat to the surrounding water by direct conduction.

Convection is the transfer of heat by the movement of heated fluids. Most home heating systems operate on the principle of convection, setting 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. Upon reaching the surface, the warmed water 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 heat transmission by electromagnetic waves of energy. Every warm object gives off waves of electromagnetic energy, which is absorbed by cool objects. Heat from the sun, electric heaters, and fireplaces is primarily radiant heat.

2-8.2 **Heat Transfer Rate.** To divers, conduction is the most significant means of transmitting heat. The rate at which heat is transferred by conduction depends on two basic factors:

- The difference in temperature between the warmer and cooler material
- The thermal conductivity of the materials

Not all substances conduct heat at the same rate. Iron, helium, and water are excellent heat conductors while air is a very poor conductor. Placing a poor heat conductor between a source of heat and another substance insulates the substance and slows the transfer of heat. Materials such as wool and foam rubber insulate the human body and are effective because they contain thousands of pockets of trapped air. The air pockets are too small to be subject to convective currents, but block conductive transfer of heat.

2-8.3 **Diver Body Temperature.** A diver will start to become chilled when the water temperature falls below a seemingly comfortable 70°F (21°C). Below 70°F, a diver wearing only a swimming suit loses heat to the water faster than his body can replace it. Unless he is provided some protection or insulation, he may quickly experience difficulties. A chilled diver cannot work efficiently or think clearly, and is more susceptible to decompression sickness.

Suit compression, increased gas density, thermal conductivity of breathing gases, and respiratory heat loss are contributory factors in maintaining a diver's body temperature. Cellular neoprene wet suits lose a major portion of their insulating properties as depth increases and the material compresses. 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 an individual gas are directly proportional to its density. Therefore, the heat lost through gas insulating barriers and respiratory heat lost to the surrounding areas increase with depth. The heat loss 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 (atmosphere absolute), to 28 percent at 7 ata, to 50 percent at 21 ata when breathing helium-oxygen. Under these circumstances, standard insulating materials are insufficient to maintain body temperatures and supplementary heat must be supplied to the body surface and respiratory gas.

2-9 PRESSURE IN DIVING

Pressure is defined as a force acting upon a particular area of matter. It is typically measured in pounds per square inch (psi) in the English system and Newton per square centimeter (N/cm^2) in the System International (SI). Underwater pressure is a result of the weight of the water above the diver and the weight of the atmosphere over the water. 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 forces acting inside of the diver's body and forces acting outside is very small. Pressure, whether of the atmosphere, seawater, or the diver's breathing gases, must always be thought of in terms of maintaining pressure balance.

2-9.1 Atmospheric Pressure. 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 per foot. Thus, for every foot of sea water, the total pressure is increased by 0.445 psi. Atmospheric pressure is constant at sea level; minor fluctuations caused by the weather are usually ignored. Atmospheric pressure acts on all things in all directions.

Most pressure gauges measure differential pressure between the inside and outside of the gauge. Thus, the atmospheric pressure does not register on the pressure gauge of a cylinder of compressed air. The initial air in the cylinder and the gauge are already under a base pressure of one atmosphere (14.7 psi or $10N/cm^2$). The gauge measures the pressure difference between the atmosphere and the increased air pressure in the tank. This reading is called *gauge pressure* and for most purposes it is sufficient.

In diving, however, 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. Table 2-10 contains conversion factors for pressure measurement units.

2-9.2 Terms Used to Describe Gas Pressure. Four terms are used to describe gas pressure:

- **Atmospheric**. Standard atmosphere, usually expressed as $10N/cm^2$, 14.7 psi, or one atmosphere absolute (1 ata).
- **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 is equal to 29.92 inches of mercury, 760 millimeters of mercury, or 1013 millibars.
- **Gauge**. Indicates the difference between atmospheric pressure and the pressure being measured.

- **Absolute**. The total pressure being exerted, i.e., gauge pressure plus atmospheric pressure.

2-9.3 **Hydrostatic Pressure.** 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 fsw), the pressure is more than 8 tons per square inch (1,100 ata). The pressure due to the weight of a water column is referred to as hydrostatic pressure.

The pressure of seawater at a depth of 33 feet equals one atmosphere. The absolute pressure, which is a combination of atmospheric and water pressure for that depth, is two atmospheres. For every additional 33 feet of depth, another atmosphere of pressure (14.7 psi) is encountered. Thus, at 99 feet, the absolute pressure is equal to four atmospheres. Table 2-1 and Figure 2-7 show how pressure increases with depth.

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)

The change in pressure with depth is so pronounced that the feet of a 6-foot tall person standing underwater are exposed to pressure that is almost 3 pounds per square inch greater than that exerted at his head.

2-9.4 **Buoyancy.** Buoyancy is the force that makes objects float. 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 applies to all objects and all fluids.

2-9.4.1 **Archimedes’ Principle.** According to Archimedes’ Principle, 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 is 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 is 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 is negative and the body will sink.

per cubic foot. Sea water is heavier, having a density of 64.0 pounds per cubic foot. Thus an object is 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.

2-9.4.2 **Diver Buoyancy.** Lung capacity has a significant effect on buoyancy of a diver. A diver with full lungs displaces a greater volume of water and, therefore, is more buoyant than with deflated lungs. Individual differences that may affect the buoyancy of a diver include bone structure, bone weight, and body fat. 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 a variable volume dry suit, he can increase or decrease the amount of air in his suit, thus changing his displacement and thereby his buoyancy. Divers usually seek a condition of neutral to slightly negative buoyancy. Negative buoyancy gives a diver in a helmet and dress a better foothold on the bottom. Neutral buoyancy enhances a scuba diver's ability to swim easily, change depth, and hover.

2-10 GASES IN DIVING

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

2-10.1 Atmospheric Air. 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 diver's 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.

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.

2-10.2 Oxygen. Oxygen (O_2) 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. From the air we breathe, only oxygen is actually used by the body. The other 79 percent of the air serves to dilute the oxygen. Pure 100 percent oxygen is often used for breathing in hospitals, aircraft, and hyperbaric medical

Table 2-2. Components of Dry Atmospheric Air.

Component	Concentration: Percent by Volume	Concentration: 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

treatment facilities. Sometimes 100 percent oxygen is used in shallow diving operations and certain phases of mixed-gas diving operations. However, breathing pure oxygen under pressure may induce the serious problems of oxygen toxicity.

2-10.3 **Nitrogen.** Like oxygen, nitrogen (N_2) is diatomic, colorless, odorless, and 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. 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, 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.

2-10.4 **Helium.** Helium (He) is 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). 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 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.

2-10.5 Hydrogen. Hydrogen (H_2) 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 visible 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.

2-10.6 Neon. Neon (Ne) is inert, monatomic, colorless, odorless, and 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.

2-10.7 Carbon Dioxide. Carbon dioxide (CO_2) 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 animal and human respiration, 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. Carbon dioxide can cause unconsciousness when breathed at increased partial pressure. In high concentrations the gas can be extremely toxic. In the case of closed and semi-closed breathing apparatus, the removal of excess carbon dioxide generated by breathing is essential to safety.

2-10.8 Carbon Monoxide. Carbon monoxide (CO) is a colorless, odorless, tasteless, and poisonous gas whose presence is difficult to detect. Carbon monoxide is formed as a product of incomplete fuel combustion, and is most commonly found in the exhaust of internal combustion engines. A diver’s air supply can be contaminated by carbon monoxide when the compressor intake is placed too close to the compressor’s engine exhaust. The exhaust gases are sucked in with the air and sent on to the diver, with potentially disastrous results. Carbon monoxide seriously interferes with the blood’s ability to carry the oxygen required for the body to function normally. The affinity of carbon monoxide for hemoglobin is approximately 210 times that of oxygen. Carbon monoxide dissociates from hemoglobin at a much slower rate than oxygen.

2-10.9 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 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.

ture." Consequently, the measurable pressures of all gases resulting from kinetic activity are affected by the same factors.

The kinetic energy of a gas is related to the speed at which the molecules are moving and the mass 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 a 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. This is illustrated in Figure 2-6.

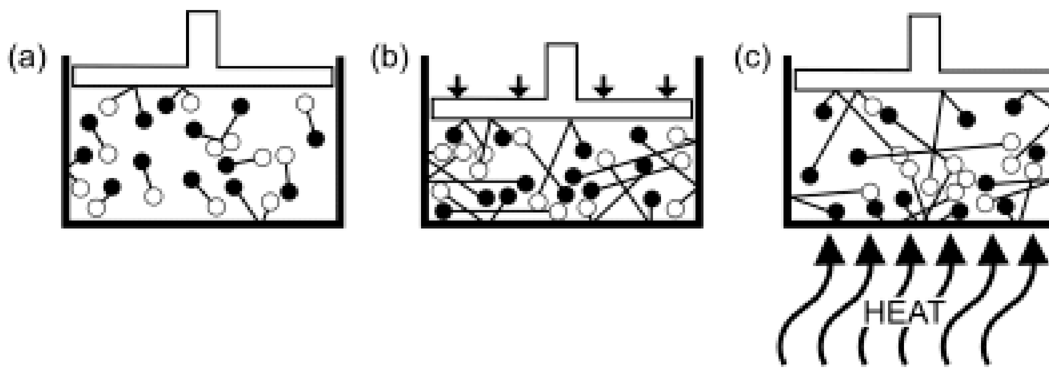

Figure 2-6. Kinetic Energy. The kinetic energy of the molecules inside the container (a) produces a constant pressure on the internal surfaces. As the container volume is decreased (b), the molecules per unit volume (density) increase and so does the pressure. As the energy level of the molecules increases from the addition of thermal energy (heat), so does the pressure (c).

2-11 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 is 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 one factor as the conditions of one or both of the other factors change. A diver needs to know how changing pressure will effect the air in his suit and lungs as he moves up and down in the water. He must be able to determine whether an air compressor can 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. This section explains the gas laws of direct concern to divers.

2-11.1 **Boyle's Law.** Boyle's law states that at constant temperature, the absolute pressure and the volume of gas are inversely proportional. As pressure increases the gas volume is reduced; as the pressure is reduced the gas volume increases. Boyle's law is important to divers because it relates to change in the volume of a gas caused by the change in pressure, due to depth, which defines the relationship of pressure and volume in breathing gas supplies.

The formula for Boyle's law is: $C = P \times V$

Where:

C = a constant
P = absolute pressure
V = volume

Boyle's law can also be expressed as: $P_1V_1 = P_2V_2$

Where:

P_1 = initial pressure
V_1 = initial volume
P_2 = final pressure
V_2 = final volume

When working with Boyle's law, pressure may be measured in atmospheres absolute. To calculate pressure using atmospheres absolute:

$$P_{ata} = \frac{\text{Depth fsw} + 33\text{ fsw}}{33\text{ fsw}} \quad \text{or} \quad P_{ata} = \frac{\text{psig} + 14.7\text{psi}}{14.7\text{psi}}$$

Sample Problem 1. 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 in the bell at 99 fsw.

1. Rearrange the formula for Boyle's law to find the final volume (V_2):

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

2. Calculate the final pressure (P_2) at 99 fsw:

$$P_2 = \frac{99\text{ fsw} + 33\text{ fsw}}{33\text{ fsw}} = 4\text{ata}$$

3. Substitute known values to find the final volume:

$$V_2 = \frac{1\text{ata} \times 24\text{ft}^3}{4\text{ata}} = 6\text{ft}^3$$

The volume of air in the open bell has been compressed to 6 $ft.^3$ at 99 fsw.

2-11.2 **Charles'/Gay-Lussac's Law.** When working with Boyle's law, the temperature of the gas is a constant value. However, temperature significantly affects the pressure and volume of a gas. Charles'/Gay-Lussac's law describes the physical relationships of temperature upon volume and pressure. Charles'/Gay-Lussac's law states that at a constant pressure, the volume of a gas is directly proportional to the change in the absolute temperature. If the pressure is kept constant and the absolute temperature is doubled, the volume will double. If the temperature decreases, volume decreases. If volume instead of pressure is kept constant (i.e., heating in a rigid container), then the absolute pressure will change in proportion to the absolute temperature.

The formulas for expressing Charles'/Gay-Lussac's law are as follows.

For the relationship between volume and temperature:

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

Where: Pressure is constant

T_1 = initial temperature (absolute)
T_2 = final temperature (absolute)
V_1 = initial volume
V_2 = final volume

And, for the relationship between pressure and temperature:

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

Where: Volume is constant

P_1 = initial pressure (absolute)
P_2 = final pressure (absolute)
T_1 = initial temperature (absolute)
T_2 = final temperature (absolute)

Sample Problem 1. An open diving bell of 24 cubic feet capacity is lowered into the ocean to a depth of 99 fsw. The surface temperature is 80°F, and the temperature at depth is 45°F. From the sample problem illustrating Boyle's law, we know that the volume of the gas was compressed to 6 cubic feet when the bell was lowered to 99 fsw. Apply Charles'/Gay-Lussac's law to determine the volume when it is effected by temperature.

1. Convert Fahrenheit temperatures to absolute temperatures (Rankine):

$$°R = °F + 460$$
$$T_1 = 80°F + 460$$
$$= 540°R$$
$$T_2 = 45°F + 460$$
$$= 505°R$$

2. Transpose the formula for Charles'/Gay-Lussac's law to solve for the final volume (V_2):

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

3. Substitute known values to solve for the final volume (V_2):

$$V_2 = \frac{6\ \text{ft.}^3 \times 505}{540}$$
$$= 5.61\ \text{ft.}^3$$

The volume of the gas at 99 fsw is 5.61 ft^3.

Sample Problem 2. A 6-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?

1. Convert gauge pressure unit to atmospheric pressure unit:

$$P_1 = 3000\ \text{psig} + 14.7\ \text{psi}$$
$$= 3014.7\ \text{psia}$$

2. Convert Fahrenheit temperatures to absolute temperatures (Rankine):

$$°R = °F + 460$$
$$T_1 = 72°F + 460$$
$$= 532°R$$
$$T_2 = 170°F + 460$$
$$= 630°R$$

3. Transpose the formula for Gay-Lussac's law to solve for the final pressure (P_2):

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

4. Substitute known values and solve for the final pressure (P_2):

$$P_2 = \frac{3014.7 \times 630}{532}$$
$$= \frac{1,899,261}{532}$$
$$= 3570.03 \text{ psia} \angle 14.7$$
$$= 3555.33 \text{ psig}$$

The pressure in the flask increased from 3000 psig to 3555.33 psig. Note that the pressure increased even though the flask's volume and the volume of the gas remained the same.

This example also 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.

2-11.3 **The General Gas Law.** Boyle, Charles, and Gay-Lussac demonstrated that temperature, volume, and pressure affect a gas in such a way that a change in one factor must be balanced by corresponding change in one or both of the others. Boyle's law describes the relationship between pressure and volume, Charles'/Gay-Lussac's law describes the relationship between temperature and volume and the relationship between temperature and pressure. The general gas law combines the laws to predict the behavior of a given quantity of gas when any of the factors change.

The formula for expressing the general gas law is: $$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

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)

Two simple rules must be kept in mind when working with the general gas law:

- There can be only one unknown value.
- The equation can be simplified 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 is of little consequence. In either case, cancel the value out of both sides of the equation to simplify the computations.

Sample Problem 1. Your ship has been assigned to salvage a sunken LCM landing craft located in 130 fsw. An exploratory dive, using scuba, is planned to survey the wreckage. The scuba cylinders are charged to 2,250 psig, which raises the temperature in the tanks to 140 °F. From experience in these waters, you know that the temperature at the operating depth will be about 40°F. Apply the general gas law to find what the gauge reading will be when you first reach the bottom. (Assume no loss of air due to breathing.)

1. Simplify the equation by eliminating the variables that will not change. The volume of the tank will not change, so V_1 and V_2 can be eliminated from the formula in this problem:

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

2. Calculate the initial pressure by converting the gauge pressure unit to the atmospheric pressure unit:

$$P_1 = 2{,}250 \text{ psig} + 14.7$$
$$= 2{,}264.7 \text{ psia}$$

3. Convert Fahrenheit temperatures to Rankine (absolute) temperatures:

Conversion formula: °R = °F + 460

$$T_1 = 140\ °F + 460$$
$$= 600\ °R$$
$$T_2 = 40\ °F + 460$$
$$= 500°R$$

4. Rearrange the formula to solve for the final pressure (P_2):

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

5. Fill in known values:

$$P_2 = \frac{2,264.7 \text{ psia} \times 500°R}{600°R}$$
$$= 1887.25 \text{ psia}$$

6. Convert final pressure (P_2) to gauge pressure:

$$P_2 = 1{,}887.25 \text{ psia} - 14.7$$
$$= 1{,}872.55 \text{ psig}$$

The gauge reading when you reach bottom will be 1,872.55 psig.

Sample Problem 2. During the survey dive for the operation outlined in Sample Problem 1, the divers determined that the damage will require a simple patch. The

Diving Supervisor elects to use surface-supplied MK 21 equipment. The compressor discharge capacity is 60 cubic feet per minute, and the air temperature on the deck of the ship is 80°F.

Apply the general gas law to determine whether the compressor can deliver the proper volume of air to both the working diver and the standby diver at the operating depth and temperature.

1. Calculate the absolute pressure at depth (P_2):

$$P_2 = \frac{130\ \text{fsw} + 33\ \text{fsw}}{33\ \text{fsw}}$$

$$= 4.93\ \text{ata}$$

2. Convert Fahrenheit temperatures to Rankine (absolute) temperatures:

Conversion formula:

$$°R = °F + 460$$

$$T_1 = 80°F + 460$$

$$= 540°R$$

$$T_2 = 40°F + 460$$

$$= 500°R$$

3. Rearrange the general gas law formula to solve for the volume of air at depth (V_2):

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

4. Substitute known values and solve:

$$V_2 = \frac{1\ \text{ata} \times 60\ \text{cfm} \times 500°R}{4.93\ \text{ata} \times 540°R}$$

$$= 11.26\ \text{acfm at bottom conditions}$$

Based upon an actual volume (displacement) flow requirement of 1.4 acfm for a deep-sea diver, the compressor capacity is sufficient to support the working and standby divers at 130 fsw.

Sample Problem 3. Find the actual cubic feet of air contained in a 700-cubic inch internal volume cylinder pressurized to 3,000 psi.

1. Simplify the equation by eliminating the variables that will not change. The temperature of the tank will not change so T_1 and T_2 can be eliminated from the formula in this problem:

$$P_1V_1 = P_2V_2$$

2. Rearrange the formula to solve for the initial volume:

$$V_1 = \frac{P_2V_2}{P_1}$$

Where:

P_1 = 14.7 psi

P_2 = 3,000 psi + 14.7 psi

V_2 = 700 in^3

3. Fill in the known values and solve for V_1:

$$V_1 = \frac{3014.7\ \text{psia} \times 700\ \text{in}^3}{14.7\ \text{psi}}$$

$$= 143,557.14\ \text{in}^3$$

4. Convert V_1 to cubic feet:

$$V_1 = \frac{143,557.14\text{in}^3}{1728\ \text{in}^3} \quad (1728\ \text{in}^3 = 1\ \text{ft}^3)$$

$$= 83.07\ \text{scf}$$

2-12 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 because it is the only one that 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 diluent 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.

2-12.1 **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 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.

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 2-3. *Partial Pressure at 1 ata.*

Gas	Percent of Component	Atmospheres Partial Pressure
N_2	78.08	0.7808
O_2	20.95	0.2095
CO_2	.03	0.0003
Other	.94	0.0094
Total	100.00	1.0000

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	0.04
Other	.94	1.29
Total	100.00	137.00

The formula for expressing Dalton's law is:

$$P_{Total} = pp_A + pp_B + pp_C + \ldots$$

Where: A, B, and C are gases and

$$pp_A = \frac{P_{Total} \times \%Vol_A}{1.00}$$

Another method of arriving at the same conclusion is to use the T formula. When using the T formula, there can be only one unknown value. Then it is merely a case of multiplying across, or dividing up to solve for the unknown value.The T formula is illustrated as:

$$\frac{\text{partial pressure}}{\text{atmosphere(s) absolute} \mid \text{\% volume (in decimal form)}}$$

Sample Problem 1. Use the T formula to calculate oxygen partial pressure given 10 ata and 16 percent oxygen.

1. Fill in the known values:

$$\frac{pp}{10 \mid .16}$$

2. Multiply the pressure by the volume to solve for the oxygen partial pressure (pp):

$$\frac{1.6\ ppO_2}{10 \mid .16}$$

The oxygen partial pressure is 1.6.

Sample Problem 2. What happens to the breathing mixture at the operating depth of 130 fsw (4.93 ata)? The air compressor on the ship is taking in air at the surface, at 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.

1. Calculate the oxygen partial pressure at depth.

$$\begin{aligned} ppO_2 &= .21\ (\text{surface}) \times 4.93\ \text{ata} \\ &= 1.03\ \text{ata} \end{aligned}$$

2. Calculate the nitrogen partial pressure at depth.

$$\begin{aligned} ppN_2 &= .79\ (\text{surface}) \times 4.93\ \text{ata} \\ &= 3.89\ \text{ata} \end{aligned}$$

3. Calculate the carbon dioxide partial pressure at depth.

$$\begin{aligned} ppCO_2 &= .0003\ (\text{surface}) \times 4.93\ \text{ata} \\ &= .0014\ \text{ata} \end{aligned}$$

2-12.1.1 **Expressing Small Quantities of Pressure.** 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. The formula used to calculate the $ppCO_2$ at 130 fsw in millimeters of mercury is:

$$ppCO_2 = \frac{0.03}{100} \times 4.93 \text{ ata} \times \frac{760\text{mmHg}}{1\text{ata}}$$
$$= 1.12\text{mmHg}$$

2-12.1.2 **Calculating Surface Equivalent Value.** From the previous calculations, it is apparent that the diver is breathing more molecules of oxygen breathing air at 130 fsw than he would be if using 100 percent oxygen 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 2 percent (0.02 ata) carbon dioxide, a level that could be readily accommodated by a normal person at one ata, the partial pressure at depth would be dangerously high—0.0986 ata (0.02 x 4.93 ata). This partial pressure is commonly referred to as a surface equivalent value (sev) of 10 percent carbon dioxide. The formula for calculating the surface equivalent value is:

$$\text{sev} = \frac{\text{pp at depth (in ata)} \times 100\%}{1 \text{ ata}}$$
$$= \frac{0.0986 \text{ ata}}{1 \text{ ata}} \times 100\%$$
$$= 9.86\% \ CO_2$$

2-12.2 **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.

An individual gas will move through a permeable membrane (a solid that permits molecular transmission) depending upon the partial pressure of the gas on each side of the membrane. If the partial pressure is higher on one side, the gas molecules will diffuse through the membrane from the higher to the lower partial pressure side until the partial pressure on sides of the membrane are equal. 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 to the side of lower concentration.

Body tissues are permeable membranes. 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.

2-12.3 Humidity. Humidity is the amount of water vapor in gaseous atmospheres. Like other gases, water vapor 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.

Humidity is related to the vapor pressure of water, and the maximum partial pressure of water vapor in the gas is governed entirely by the temperature of the gas. As the gas temperature increases, more molecules of water can be maintained in the gas until a new equilibrium condition and higher maximum partial pressure are established. As a gas cools, water vapor in the gas condenses until a lower partial pressure condition exists regardless of the total pressure of the gas. The temperature at which a gas is saturated with water vapor is called the *dewpoint*.

In proper concentrations, water vapor in a diver's breathing gas can be beneficial to the diver. Water vapor moistens body tissues, thus keeping the diver comfortable. As a condensing liquid, however, water vapor can freeze and block air passageways in hoses and equipment, fog a diver's faceplate, and corrode his equipment.

2-12.4 Gases in Liquids. When a gas comes in contact with a liquid, a portion of the gas molecules enters into solution with the liquid. The gas is said to be *dissolved* in the liquid. Solubility is vitally important because significant amounts of gases are dissolved in body tissues at the pressures encountered in diving.

2-12.5 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, temperature and pressure greatly affect the quantity of gas that will be absorbed. Because a diver is always operating under unusual conditions of pressure, understanding this factor is particularly important.

2-12.6 Henry's Law. Henry's law states: "The amount of any given gas that will dissolve in a liquid at a given temperature is directly proportional to the partial pressure of that gas." 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.

2-12.6.1 **Gas Tension.** When a gas-free liquid is first exposed to a gas, quantities of gas molecules rush to enter the solution, pushed along by the partial pressure of the gas. As the molecules enter the liquid, they add to a state of gas tension. Gas tension 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*. The pressure gradient indicates the rate at which the gas enters or leaves the solution.

2-12.6.2 **Gas Absorption.** 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 changes and tissues 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* or *offgassing*. In air diving, nitrogen absorption occurs when a diver is exposed to an increased nitrogen partial pressure. As pressure decreases, the nitrogen is eliminated. 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 as it flows through the body. 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 small compared to the mass of the tissue, but over a period of time the gas delivered to the tissue causes it to become equilibrated with the gas carried in the blood. As the number of gas molecules in the liquid increases, the tension increases until it reaches a value equal to the partial pressure. When the tension equals the partial pressure, the liquid is saturated with the gas and the pressure gradient is zero. Unless the temperature or pressure changes, 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.

2-12.6.3 **Gas Solubility.** The solubility of gases is affected by temperature—the lower the temperature, the higher the solubility. As the temperature of a solution increases, some of the dissolved gas leaves the solution. The bubbles rising 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 are 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 that becomes dissolved is also 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.

The dissolved gas in a diver's body, regardless of quantity, depth, or pressure, remains in solution as long as the pressure is maintained. However, as the diver ascends, more and more of the dissolved gas comes out of solution. If his ascent rate is controlled (i.e., through the use of the decompression tables), the dissolved gas is carried to the lungs and exhaled before it accumulates to form significant 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 decompression sickness.

Table 2-5. *Symbols and Values.*

Symbol	Value
°F	Degrees Fahrenheit
°C	Degrees Celsius
°R	Degrees Rankine
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
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
BTU	British Thermal Unit
cm^3	Cubic Centimeter
kw hr	Kilowatt Hour
mb	Millibars

Table 2-6. ***Buoyancy (In Pounds).***

Fresh Water	(*V cu ft* x 62.4) - *Weight of Unit*
Salt Water	(*V cu ft* x 64) - *Weight of Unit*

Table 2-7. *Formulas for Area.*

Square or Rectangle	A = L x W
Circle	$A = 0.7854 \times Dia^2$ *or* $A = \pi r^2$

Table 2-8. *Formulas for Volumes.*

Compartment	$V = L \times W \times H$
Sphere	$= \pi \times 4/3 \times r^3$ $= 0.5236 \times Dia^3$
Cylinder	$V = \pi \times r^2 \times L$ $= \pi \times 1/4 \times Dia^2 \times L$ $= 0.7854 \times Dia^2 \times L$

Table 2-9. *Formulas for Partial Pressure/Equivalent Air Depth.*

Partial Pressure Measured in psi	$pp = (D + 33\ fsw) \times 0.445\ psi \times \left(\frac{\%V}{100\%}\right)$
Partial Pressure Measured in ata	$pp = \frac{D + 33\ fsw}{33\ fsw} \times \frac{\%V}{100\ \%}$
Partial Pressure Measured in fsw	$pp = (D + 33fsw) \times \frac{\%V}{100\%}$
T formula for Measuring Partial Pressure	$\frac{pp}{ata \mid \%}$
Equivalent Air Depth for N_2O_2 Diving Measured in fsw	$EAD = \left[\frac{(1.0 \angle O_2\%)(D + 33)}{.79}\right] \angle 33$
Equivalent Air Depth for N_2O_2 Diving Measured in meters	$EAD = \left[\frac{(1.0 \angle O_2\%)(M + 10)}{.79}\right] \angle 10$

Table 2-10. *Pressure Equivalents.*

				Columns of Mercury at 0°C		Columns of Water* at 15° C			
Atmos-pheres	**Bars**	**10 Newton Per Square Centimeter**	**Pounds Per Square Inch**	**Meters**	**Inches**	**Meters**	**Inches**	**Feet (FW)**	**Feet (FSW)**
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	19.33369	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

1. Fresh Water (FW) = 62.4 lbs/ft^3; Salt Water (fsw) = 64.0 lbs/ft^3.
2. The SI unit for pressure is Kilopascal (KPA)—1KG/CM^2 = 98.0665 KPA and by definition 1 BAR = 100.00 KPA @ 4ºC.
3. In the metric system, 10 MSW is defined as 1 BAR. Note that pressure conversion from MSW to FSW is different than length conversion; i.e., 10 MSW = 32.6336 FSW and 10 M = 32.8083 feet.

Table 2-11. *Volume and Capacity Equivalents.*

Cubic Centi-meters	**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	49511×10^{-3}	3785.33	3.78533	8	4	1

Table 2-12. *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}	5.3659×10^{-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	$1.8288 \times 10\text{-}^{3}$	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	80	1.60935	1	0.868393
185325	72962.4	6080.4	2026.73	1853.25	1013.36	1.85325	1.15155	1

Table 2-13. *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 2-14. *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	0.0223639	0.0194673
100	1	60	3.6	3.28083	196.85	2.23693	1.9473
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 2-15. *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	15432.4	0.035274	2.2046×10^{-3}	1.1023×10^{-6}	9.842×10^{-7}	0.000001
6.4799×10^{-5}	0.6047989	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	4.4543×10^{-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 2-16. *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}
1.3566	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}	1.596×10^{-3}	1	3.96832
1054.87	1.0549×10^{10}	778.155	2.930×10^{-4}	3.93×10^{-4}	0.251996	1

Table 2-17. *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 2-18. *Temperature Equivalents.*

Conversion Formulas: $°C = (°F \angle 32) \times \frac{5}{9}$ $\quad$ $°F = \left(\frac{9}{5} \times °C\right) + 32$

°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

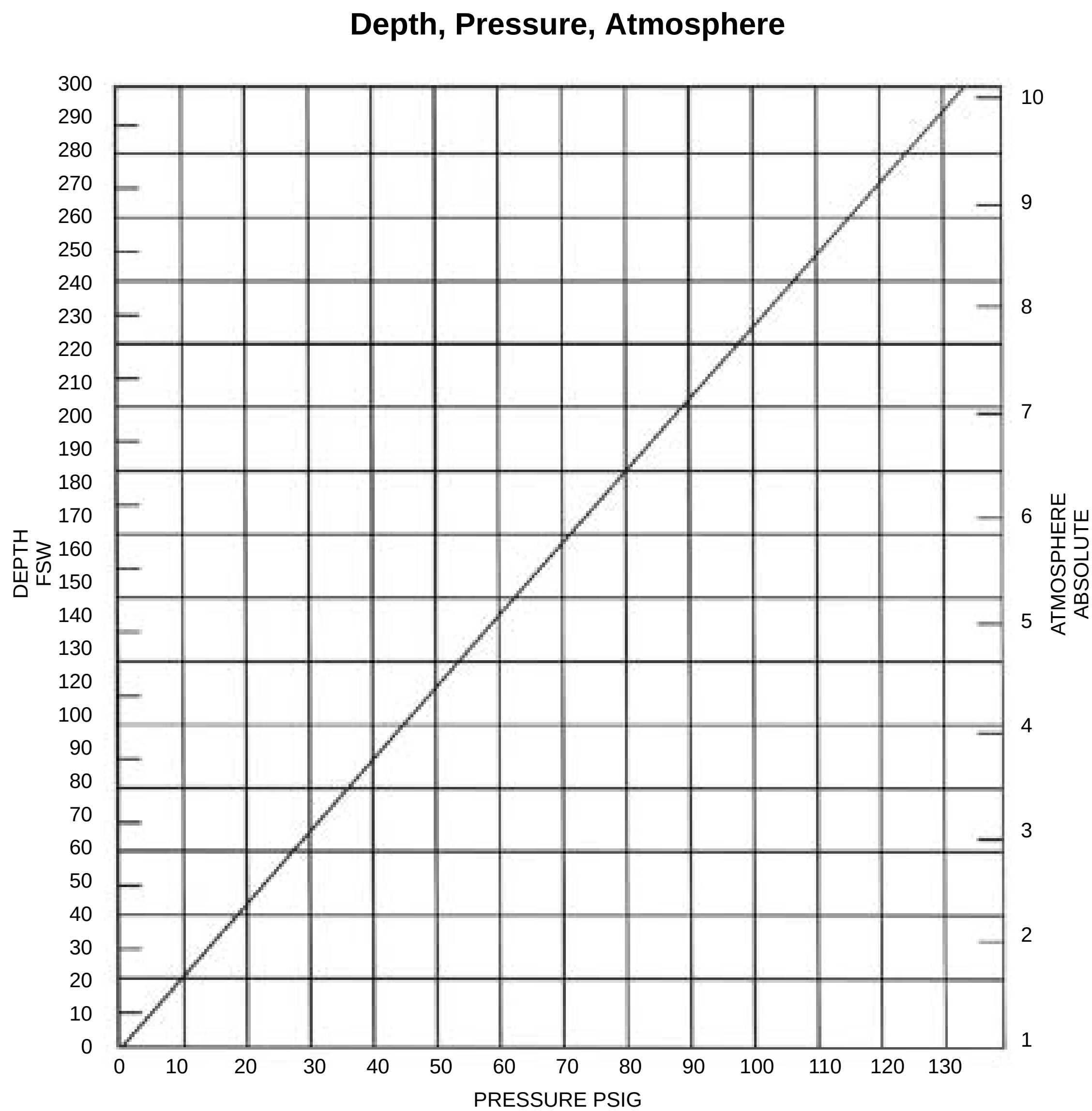

Figure 2-7. Depth, Pressure, Atmosphere Graph.

CHAPTER 3

Underwater Physiology and Diving Disorders

3-1 INTRODUCTION

3-1.1 Purpose. This chapter provides basic information on the changes in human anatomy and physiology that occur while working in the underwater environment. It also discusses the diving disorders that result when these anatomical or physiological changes exceed the limits of adaptation

3-1.2 Scope. Anatomy is the study of the structure of the organs of the body. Physiology is the study of the processes and functions of the body. This chapter explains the basic anatomical and physiological changes that occur when diver enters the water and is subject to increased ambient pressure. A diver's knowledge of these changes is as important as his knowledge of diving gear and procedures. When the changes in normal anatomy or physiology exceed the limits of adaptation, one or more pathological states may emerge. These pathological states are called diving disorders and are also discussed in this chapter. Safe diving is only possible when the diver fully understands the fundamental processes at work on the human body in the underwater environment

3-1.3 General. A body at work requires coordinated functioning of all 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. The individual is generally unaware that these functions are taking place.

As efficient as it is, the human 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, if not understood, can give rise to serious accidents.

3-2 THE NERVOUS SYSTEM

The nervous system coordinates all body functions and activities. The nervous system comprises the brain, spinal cord, and a complex network of nerves that course through the body. The brain and spinal cord are collectively referred to as the *central nervous system* (CNS). Nerves originating in the brain and spinal cord and traveling to peripheral parts of the body form the *peripheral nervous system* (PNS). The peripheral nervous 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.

3-3 THE CIRCULATORY SYSTEM

The circulatory system consists of the heart, arteries, veins, and capillaries. The circulatory system carries oxygen, nutrients, and hormones to every cell of the body, and carries away carbon dioxide, waste chemicals, and heat. Blood circulates through a closed system of tubes that includes the lung and tissue capillaries, heart, arteries, and veins.

3-3.1 **Anatomy.** Every part of the body is completely interwoven with intricate networks of extremely small blood vessels called capillaries. The very large surface areas required for ample diffusion of gases in the lungs and tissues are provided by the thin walls of the capillaries. In the lungs, capillaries surround the tiny air sacs (alveoli) so that the blood they carry can exchange gases with air.

3-3.1.1 **The Heart.** 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 that forms its walls and provides the pumping action. The heart is located in the front and center of the chest cavity between the lungs, directly behind the breastbone (sternum).

The interior of the heart is divided lengthwise into halves, separated by a wall of tissue called a septum. The two halves have no direct connection 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).

3-3.1.2 **The Pulmonary and Systemic Circuits.** The circulatory system consists of two circuits with the same blood flowing through the body. 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. 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 muscle or organ capillary has lost most of its oxygen and is loaded with carbon dioxide. The blood flows through the body's veins to the 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. The blood flows

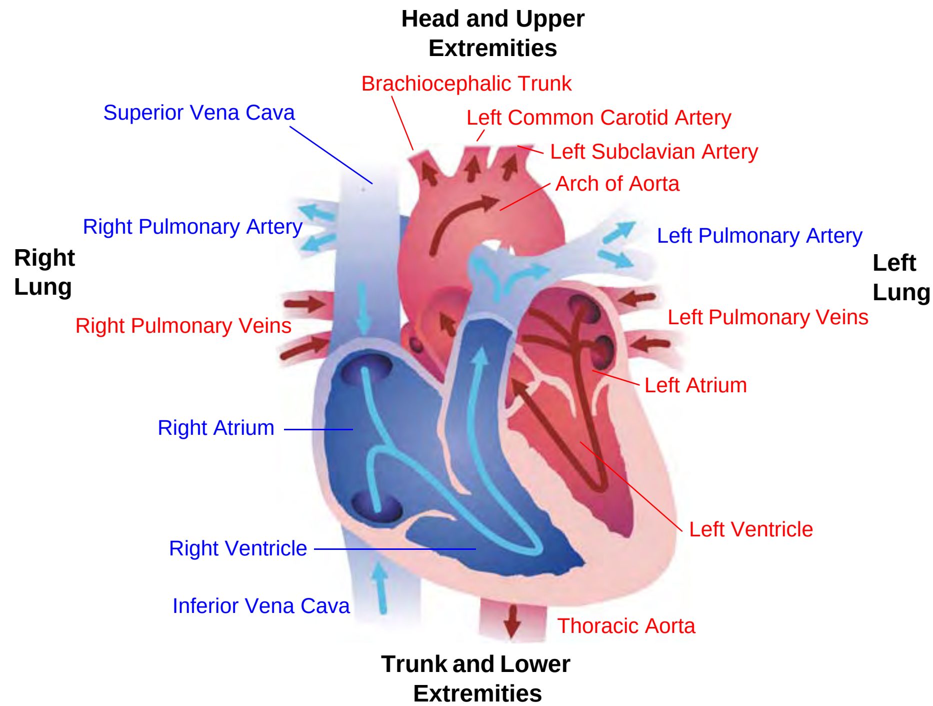

Figure 3-1. The Heart's Components and Blood Flow.

through the main veins into the right atrium and then through the tricuspid valve into the right ventricle.

The next heart contraction forces the blood through the pulmonic valve into the pulmonary artery. The blood then passes 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, into successively smaller vessels until reaching the capillaries, where oxygen is exchanged for carbon dioxide. The blood is now ready for another trip to the lungs and back again. Figure 3-2 shows how the pulmonary circulatory system is arranged.

The larger blood vessels are somewhat elastic and have muscular walls. They stretch and contract as blood is pumped from the heart, maintaining a slow but adequate flow (perfusion) through the capillaries.

3-3.3 **Blood Components.** The average human body contains approximately 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.

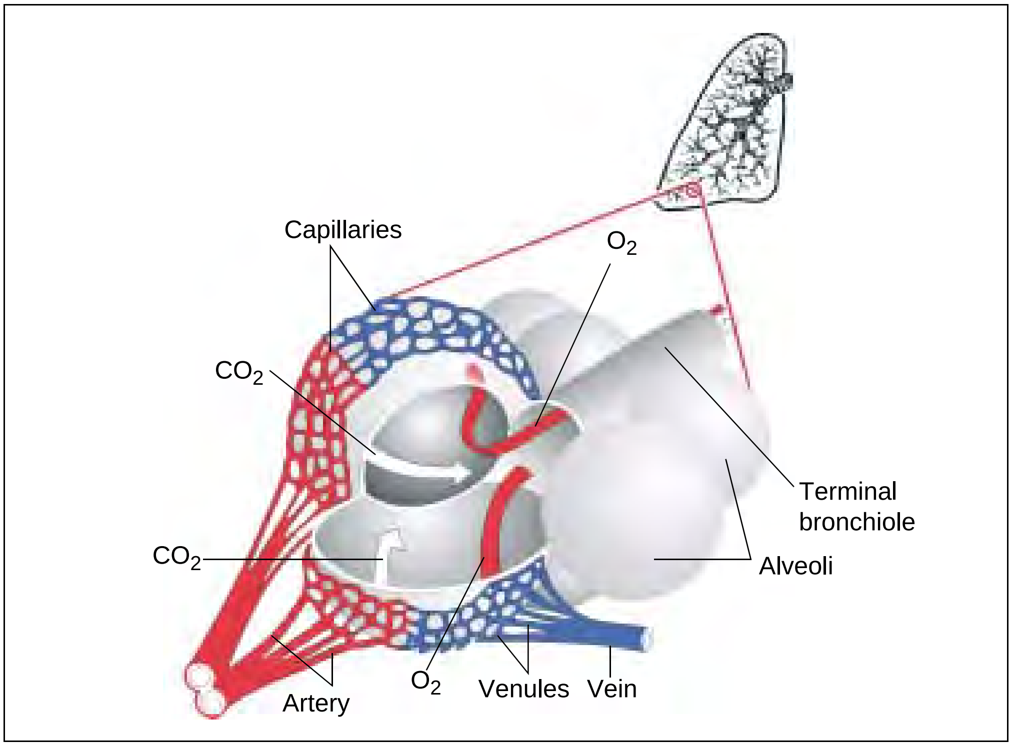

Figure 3-2. Respiration and Blood Circulation. The lung's gas exchange system is essentially three pumps. The thorax, a gas pump, moves air through the trachea and bronchi to the lung's air sacs. These sacs, the alveoli, are shown with and without their covering of pulmonary capillaries. The heart's right ventricle, a fluid pump, moves blood that 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 via the arterial system to the systemic capillaries which deliver oxygen to and collect carbon dioxide from the body's cells.

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 dark 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 tissue 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 also plays an important part in transporting carbon dioxide. 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.

Blood also contains infection-fighting white blood cells, and platelets, which are cells essential in blood coagulation. Plasma is the colorless, watery 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, even the slightest bodily injury could cause death.

3-4 THE RESPIRATORY SYSTEM

Every cell in the body must obtain energy to maintain its life, growth, and function. Cells obtain their energy from oxidation, which is a slow, controlled burning of food materials. Oxidation requires fuel and oxygen. Respiration is the process of exchanging oxygen and carbon dioxide during oxidation and releasing energy and water.

3-4.1 **Gas Exchange.** Few body cells are close enough to the surface to have any chance of obtaining oxygen and expelling carbon dioxide by direct air diffusion. Instead, the gas exchange takes place via the circulating blood. The blood is exposed to air over a large diffusing surface as 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 that are protected inside the bony cage of the chest. This makes it necessary to continually move air in and out of the space. The processes of breathing and the exchange of gases in the lungs are referred to as *ventilation* and *pulmonary gas exchange*, respectively.

3-4.2 **Respiration Phases.** The complete process of respiration includes six important phases:

1. Ventilation of the lungs with fresh air
2. Exchange of gases between blood and air in lungs
3. Transport of gases by blood
4. Exchange of gases between blood and tissue fluids
5. Exchange of gases between the tissue fluids and cells
6. Use and production of gases by cells

If any one of the processes stops or is seriously hindered, the affected cells cannot function normally or survive for any length of time. Brain tissue cells, for example, stop working almost immediately and will either die or be permanently injured in a few minutes if their oxygen supply is completely cut off.

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 speech production by providing air to the larynx and the vocal chords. The respiratory tract is divided into upper and lower tracts.

3-4.3 **Upper and Lower 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.

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 surface area for the exchange of oxygen and carbon dioxide that occurs between the internal alveolar surface and the tiny capillaries surrounding the external alveolar wall.

3-4.4 **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, expelling the used air.

3-4.4.1 **The Chest Cavity.** The 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.

3-4.4.2 **The Lungs.** The lungs are a pair of light, spongy organs in the chest and are the main component of the respiratory system (see Figure 3-4). 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 expandable air sacs (alveoli) connected to air passages. These passages branch and rebranch like the

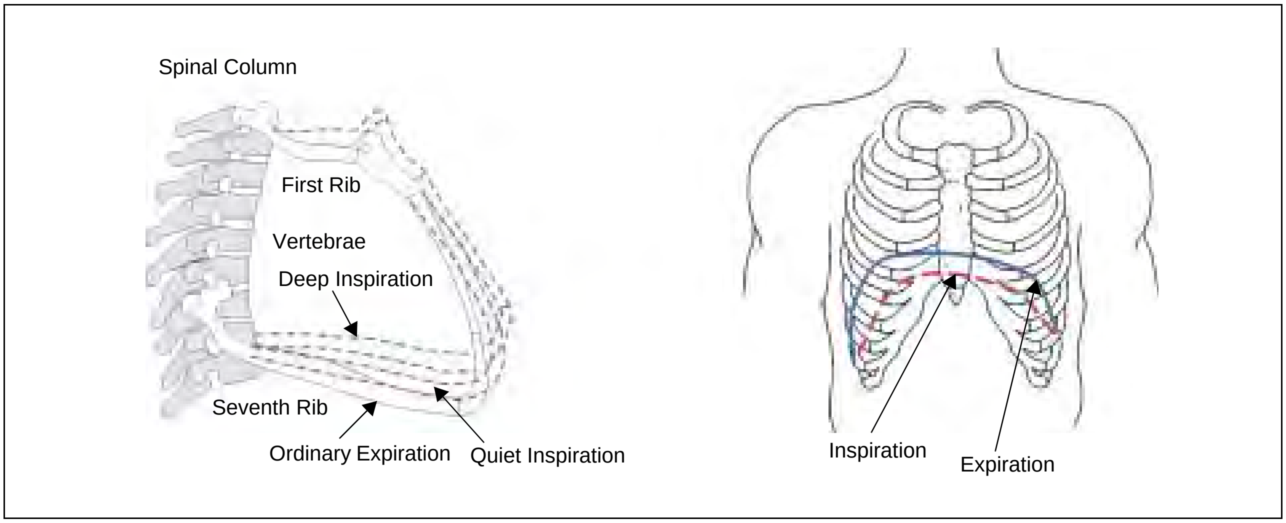

Figure 3-3. Inspiration Process. Inspiration involves both raising the rib cage (left panel) and lowering the diaphragm (right panel). Both movements enlarge the volume of the thoracic cavity and draw air into the lung.

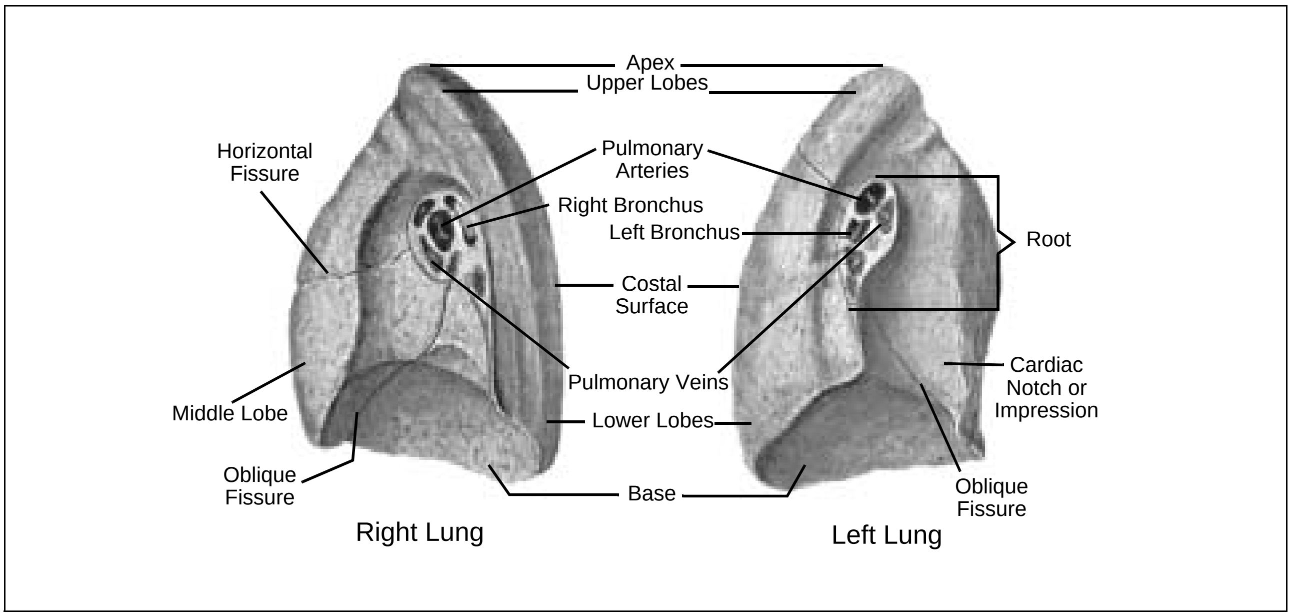

Figure 3-4. Lungs Viewed from Medial Aspect.

twigs of a tree. Air entering 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 vessels that make up the 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.

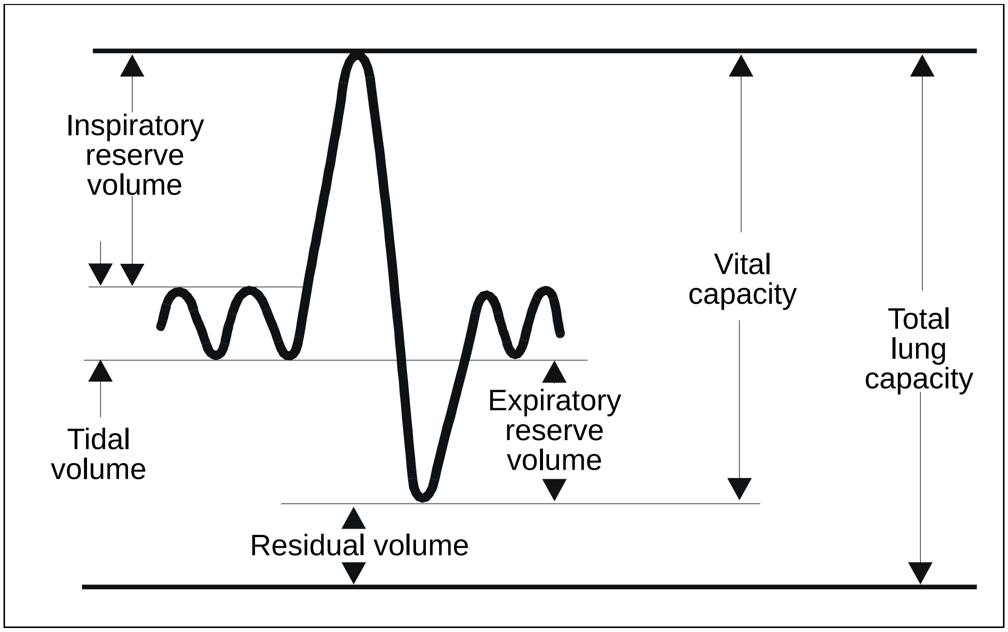

Figure 3-5. Lung Volumes The heavy line is a tracing, derived from a subject breathing to and from a sealed recording bellows. Following several normal tidal breaths, the subject inhales maximally, then exhales maximally. The volume of air moved during this maximal effort is called the vital capacity. During exercise, 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.

3-4.5 **Respiratory Tract Ventilation Definitions.** Ventilation of the respiratory system establishes 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. The *respiratory cycle* is one complete breath consisting of an inspiration and exhalation, including any pause between the movements.

Respiratory Rate. The number of complete respiratory cycles that take place in 1 minute is the respiratory rate. An adult at rest normally has a respiratory rate of approximately 12 to 16 breaths per minute.

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

Vital Capacity. *Vital capacity* is 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. *Tidal volume* is the volume of air moved in or out of the lungs during a single normal respiratory cycle. The tidal volume generally averages about one-half liter for an adult at rest. Tidal volume increases considerably during physical exertion, and may be as high as 3 liters during severe work.

Respiratory Minute Volume. The *respiratory minute volume* (RMV) is the total amount of air moved in or out of the lungs in a minute. The respiratory minute volume is calculated by multiplying the tidal volume by the respiratory rate. 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 and Maximum Ventilatory Volume. The *maximum breathing capacity* (MBC) and *maximum voluntary ventilation* (MVV) are the greatest respiratory minute volumes that a person can produce during a short period of extremely forceful breathing. In a healthy young man, they may average as much as 180 liters per minute (the range is 140 to 240 liters per minute).

Maximum Inspiratory Flow Rate and Maximum Expiratory Flow Rate. The *maximum inspiratory flow rate* (MIFR) and *maximum expiratory flow rate (*MEFR) are 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. Flow rates are usually expressed in liters per second.

Respiratory Quotient. *Respiratory quotient* (RQ) is the ratio of the amount of carbon dioxide produced to the amount of oxygen consumed during cellular processes 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 ratio is significant when calculating the amount of carbon dioxide produced as oxygen is used at various workloads while using a closed-circuit breathing apparatus. The duration of the carbon dioxide absorbent canister can then be compared to the duration of the oxygen supply.

Respiratory Dead Space. *Respiratory dead space* refers to 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 occupying the dead space at the end of expiration is rebreathed in the following inspiration. 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, the air that is taken into the lungs (inspired air) is a mixture of fresh and dead space gases.

3-4.6 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.

When 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 absorbed by the cells and carbon dioxide is picked up from these cells. When the blood returns to the pulmonary capillaries and is exposed to the alveolar air, the partial pressures of gases between the blood and the alveolar air are again equalized.

Carbon dioxide diffuses from the blood into the alveolar air, lowering its partial pressure, and oxygen is absorbed by the blood from the alveolar air, increasing its partial 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.

3-4.7 **Breathing Control.** The amount of oxygen consumed and carbon dioxide produced increases markedly when a diver is working. The amount of blood 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 partial pressure (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 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 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.

3-4.8 **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. Oxygen consumption is a measure of energy expenditure and is closely linked to the respiratory processes of ventilation and carbon dioxide production.

Oxygen consumption is measured in liters per minute (l/min) at Standard Temperature (0°C, 32°F) and Pressure (14.7 psia, 1 ata), Dry Gas (STPD). These rates of oxygen consumption are not depth dependent. This means that a fully charged MK 16 oxygen bottle containing 360 standard liters (3.96 scf) of usable gas will last 225 minutes at an oxygen consumption rate of 1.6 liters per minute at any depth, provided no gas leaks from the rig.

Minute ventilation, or respiratory minute volume (RMV), is measured at BTPS (body temperature 37°C/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. 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 a diver inhales is depth dependent. At the surface, a diver swimming at 0.5 knot inhales 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 inhales 20 l/min at BTPS, but the gas is twice as dense; thus, the inhalation 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.

Carbon dioxide production depends only on the level of exertion and can be assumed to be independent of depth. Carbon dioxide production and RQ are used to compute ventilation rates for chambers and free-flow diving helmets. 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.

3-5 RESPIRATORY PROBLEMS IN DIVING.

Physiological problems often occur when divers are 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 is only marginally aware of small changes. The extra work of breathing reduces the diver's ability to do heavy work at depth, but moderate work can be done with adequate equipment at the maximum depths currently achieved in diving.

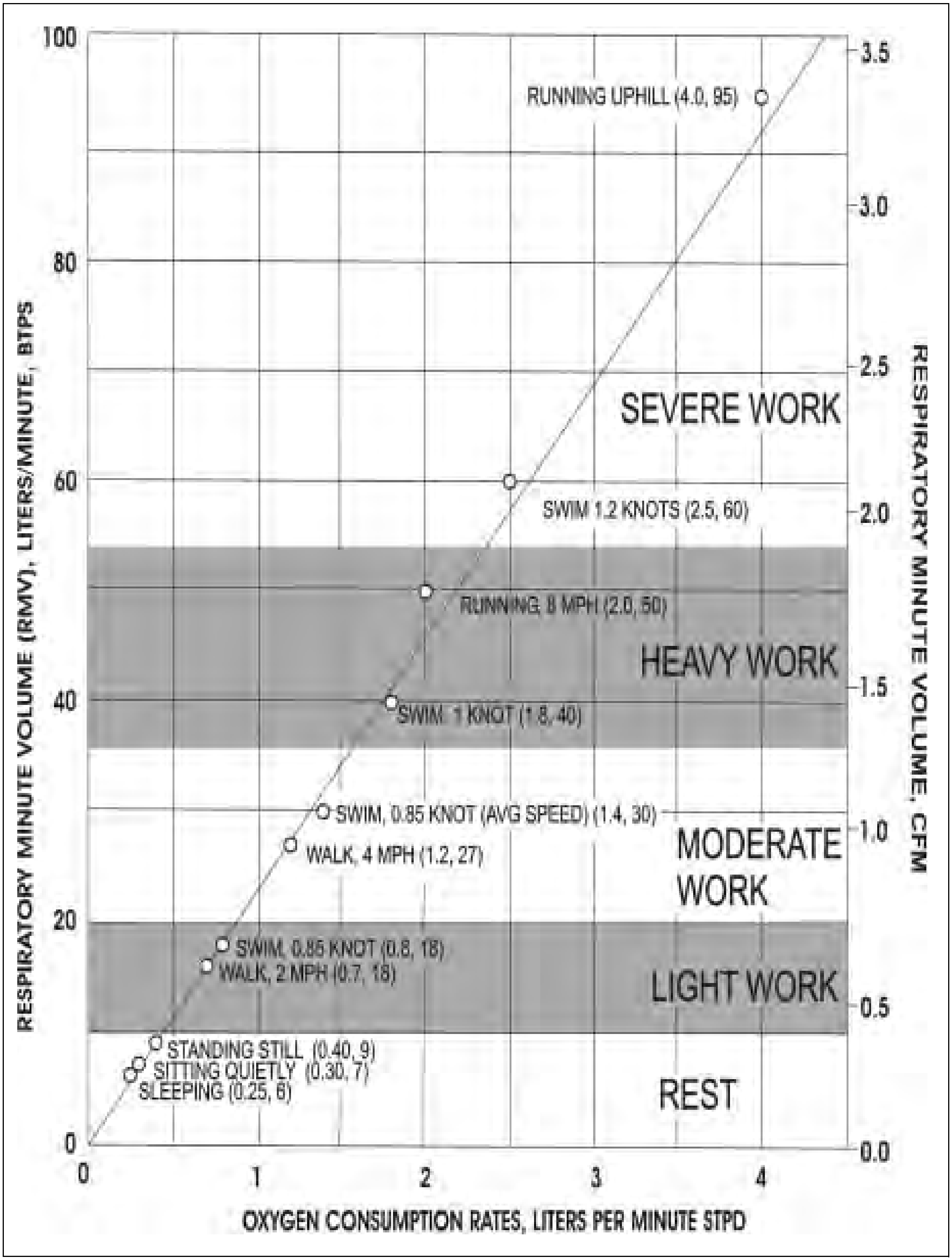

Figure 3-6. Oxygen Consumption and RMV at Different Work Rates.

3-5.1 **Oxygen Deficiency (Hypoxia).** Hypoxia, is an abnormal deficiency of oxygen in the arterial blood. Severe hypoxia will impede the normal function of cells and eventually kill them. The brain is the most vulnerable organ in the body to the effects of hypoxia.

The partial pressure of oxygen (ppO_2) determines whether the amount of oxygen in a breathing medium is adequate. Air contains approximately 21 percent oxygen and provides an ample ppO_2 of about 0.21 ata at the surface. A drop in ppO_2 below 0.16 ata causes the onset of hypoxic symptoms. Most individuals become hypoxic to the point of helplessness at a ppO_2 of 0.11 ata and unconscious at a ppO_2 of 0.10 ata. Below this level, permanent brain damage and eventually death will occur. In diving, a lower percentage of oxygen will suffice as long as the total pressure is sufficient to maintain an adequate ppO2. For example, 5 percent oxygen gives 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 were not increased.

3-5.1.1 **Causes of Hypoxia.** The causes of hypoxia vary, but all interfere with the normal oxygen supply to the body. For divers, interference of oxygen delivery can be caused by:

- Improper line up of breathing gases resulting in a low partial pressure of oxygen in the breathing gas supply.
- Partial or complete blockage of the fresh gas injection orifice in a semiclosed-circuit UBA. Failure of the oxygen addition valve in closed circuit rebreathers like the MK 16.
- Inadequate purging of breathing bags in closed-circuit oxygen rebreathers like the MK 25.
- Blockage of all or part of the air passages by vomitus, secretions, water, or foreign objects.
- Collapse of the lung due to pneumothorax.
- Paralysis of the respiratory muscles from spinal cord injury.
- Accumulation of fluid in the lung tissues (pulmonary edema) due to diving in cold water while overhydrated, negative pressure breathing, inhalation of water in a near drowning episode, or excessive accumulation of venous gas bubbles in the lung during decompression. The latter condition is referred to as “chokes”. Pulmonary edema causes a mismatch of alveolar ventilation and pulmonary blood flow and decreases the rate of transfer of oxygen across the alveolar capillary membrane.
- Carbon monoxide poisoning. Carbon monoxide interferes with the transport of oxygen by the hemoglobin in red blood cells and blocks oxygen utilization at the cellular level.

- Breathholding. During a breathhold the partial pressure of oxygen in the lung falls progressively as the body continues to consume oxygen. If the breathhold is long enough, hypoxia will occur.

3-5.1.2 **Symptoms of Hypoxia.** The symptoms of hypoxia include:

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

Brain tissue is by far the most susceptible to the effects of hypoxia. Unconsciousness and death can occur from brain hypoxia before the effects on other tissues become very prominent.

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.

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. 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.

If hypoxia develops gradually, symptoms of interference with brain function will appear. 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.

3-5.1.3 **Treatment of Hypoxia.** A diver suffering from severe hypoxia must be rescued promptly. Treat with basic first aid and 100% oxygen. If a victim of hypoxia is given gas with adequate oxygen content before his breathing stops, he usually regains consciousness shortly and recovers 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. Refer to Volume 4 for information on treatment of hypoxia arising in specific operational environments for dives involving semi-closed and closed-circuit rebreathers.

3-5.1.4 **Prevention of Hypoxia.** Because of its insidious nature and potentially fatal outcome, preventing hypoxia is essential. In open-circuit SCUBA and helmets, hypoxia is unlikely unless the supply gas has too low an oxygen content. On mixed-gas operations, strict attention must be paid to gas analysis, cylinder lineups and predive checkout procedures. In closed and semi-closed circuit rebreathers, a malfunction can cause hypoxia even though the proper gases are being used. Electronically controlled, fully closed-circuit Underwater Breathing Apparatus (UBAs), like the MK 16, have oxygen sensors to read out oxygen partial pressure, but divers must be constantly alert to the possibility of hypoxia from a UBA malfunction. **To prevent hypoxia, oxygen sensors should be monitored closely throughout the dive. MK 25 UBA breathing bags should be purged in accordance with Operating Procedures (OPs).** Recently surfaced mixed-gas chambers should not be entered until after they are thoroughly ventilated with air.

3-5.2 **Carbon Dioxide Retention (Hypercapnia).** Hypercapnia is an abnormally high level of carbon dioxide in the blood and body tissues.

3-5.2.1 **Causes of Hypercapnia.** In diving operations, hypercapnia is generally the result of a buildup of carbon dioxide in the breathing supply or an inadequate respiratory minute volume. The principal causes are:

- Excess carbon dioxide levels in compressed air supplies due to improper placement of the compressor inlet.
- Inadequate ventilation of surface-supplied helmets or UBAs.
- Failure of carbon dioxide absorbent canisters to absorb carbon dioxide or incorrect installation of breathing hoses in closed or semi-closed circuit UBAs.
- Inadequate lung ventilation in relation to exercise level. The latter may be caused by skip breathing, increased apparatus dead space, excessive breathing resistance, or increased oxygen partial pressure.

Excessive breathing resistance is an important cause of hypercapnia and arises from two sources: flow resistance and static lung load. Flow resistance results from the flow of dense gas through tubes, hoses, and orifices in the diving equipment and through the diver's own airways. As gas density increases, a larger driving pressure must be applied to keep gas flowing at the same rate. The diver has 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 increase. Because the respiratory muscles can only exert so much effort to inhale and exhale, a point is reached when further increases cannot occur. At this point, metabolically produced carbon dioxide is not adequately eliminated and increases in the blood and tissues, causing symptoms of hypercapnia. Symptoms of hypercapnia usually become apparent when divers attempt heavy work at depths deeper then 120 FSW on air or deeper than 850 FSW on helium-oxygen. At very great depths (1,600-2,000 FSW), shortness of breath and other signs of carbon dioxide toxicity may occur even at rest.

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 supplies gas at a slight positive pressure once the demand valve has opened. If the diver flips onto his back, the regulator diaphragm is shallower than his mouth and the regulator supplies gas at a slightly negative pressure. Inhalation is harder but exhalation is easier because the exhaust ports are above the mouth and at a slightly lower pressure.

Static lung loading is more apparent in closed and semi-closed circuit underwater breathing apparatus such as the MK 25 and MK 16. When swimming horizontally with the MK 16, 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 at the mouth. Inhalation becomes easier than exhalation. Static lung load is an important contributor to hypercapnia.

Excessive breathing resistance may cause shortness of breath and a sensation of labored breathing (dyspnea) without any increase in blood carbon dioxide level. In this case, the sensation of shortness of breath is due to activation of pressure and stretch receptors in the airways, lungs, and chest wall rather than activation of the chemoreceptors in the brain stem and carotid and aortic bodies. Ususally, both types of activation are present when breathing resistance is excessive

3-5.2.2 Symptoms of Hypercapnia. Hypercapnia affects the brain differently than hypoxia does. However, it can result in similar symptoms. Symptoms of hypercapnia include:

- Increased breathing rate
- Shortness of breath, sensation of difficult breathing or suffocation (dyspnea)
- Confusion or feeling of euphoria
- Inability to concentrate
- Increased sweating

- Drowsiness
- Headache
- Loss of consciousness
- Convulsions

The increasing level of carbon dioxide in the blood stimulates the respiratory center to increase the breathing rate and volume. The pulse rate also often increases. On dry land, the increased breathing rate is easily noticed and uncomfortable enough to warn the victim before the rise in $ppCO_2$ becomes dangerous. This is usually not the case in diving. Factors such as water temperature, work rate, increased breathing resistance, and an elevated ppO2 in the breathing mixture may produce changes in respiratory drive that mask changes caused by excess carbon dioxide. This is especially true in closed-circuit UBAs, particularly 100-percent oxygen rebreathers. In cases where the ppO_2 is above 0.5 ata, the shortness of breath usually associated with excess carbon dioxide may not be prominent 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. A similar situation can occur in cold water. Exposure to cold water often results in an increase in respiratory rate. This increase can make it difficult for the diver to detect an increase in respiratory rate related to a buildup of carbon dioxide.

Injury from hypercapnia is usually due to secondary effects such as drowning or injury caused by decreased mental function or unconsciousness. A diver who loses consciousness because of excess carbon dioxide in his breathing medium and does not inhale water generally revives rapidly when given fresh air and usually feels normal within 15 minutes. The after effects 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. If breathing resistance was high, the diver may note some respiratory muscle soreness post-dive.

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 CNS oxygen toxicity. Excess carbon dioxide during a dive is also believed to increase the likelihood of decompression sickness, but the reasons are less clear.

The effects of nitrogen narcosis and hypercapnia are additive. A diver under the influence of narcosis will probably not notice the warning signs of carbon dioxide intoxication. Hypercapnia in turn will intensify the symptoms of narcosis.

3-5.2.3 **Treatment of Hypercapnia.** Hypercapnia is treated by:

- Decreasing the level of exertion to reduce CO_2 production
- Increasing helmet and lung ventilation to wash out excess CO_2
- Shifting to an alternate breathing source or aborting the dive if defective equipment is the cause.

Because the first sign of hypercapnia may be unconsciousness and it may not be readily apparent whether the cause is hypoxia or hypercapnia. It is important to rule out hypoxia first becauses of the significant potential for brain damage in hypoxia. Hypercapnia may cause unconsciousness, but by itself will not injure the brain permanently.

3-5.2.4 **Prevention of Hypercapnia.** In surface-supplied diving, hypercapnia is prevented by ensuring that gas supplies do not contain excess carbon dioxide, by maintaining proper manifold pressure during the dive and by ventilating the helmet frequently with fresh gas. For dives deeper than 150 fsw, helium-oxygen mixtures should be used to reduce breathing resistance. In closed or semiclosed-circuit UBAs, hypercapnia is prevented by carefully filling the CO_2 absorbent canister and limiting dive duration to established canister duration limits. For dives deeper than 150 fsw, helium-oxygen mixtures should be used to reduce breathing resistance.

3-5.3 **Asphyxia.** *Asphyxia* is a condition where breathing stops and both hypoxia and hypercapnia occur simultaneously. Asphyxia will occur when there is no gas to breathe, when the airway is completely obstructed, when the respiratory muscles become paralyzed, or when the respiratory center fails to send out impulses to breathe. Running out of air is a common cause of asphyxia in SCUBA diving. Loss of the gas supply may also be due to equipment failure, for example regulator freeze up. Divers who become unconscious as a result of hypoxia, hypercapnia, or oxygen toxicity may lose the mouthpiece and suffer asphyxia. Obstruction of the airway can be caused by injury to the windpipe, the tongue falling back in the throat during unconsciousness, or the inhalation of water, saliva, vomitus or a foreign body. Paralysis of the respiratory muscles may occur with high cervical spinal cord injury due to trauma or decompression sickness. The respiratory center in the brain stem may become non-functional during a prolonged episode of hypoxia.

3-5.4 **Drowning/Near Drowning.** Drowning is fluid induced asphyxia. *Near drowning* is the term used when a victim is successfully resuscitated following a drowning episode.

3-5.4.1 **Causes of Drowning.** A swimmer or diver 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. Drowning in a hard-hat diving rig 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 regardless of 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.

3-5.4.2 **Symptoms of Drowning/Near Drowning.**

- Unconsciousness
- Pulmonary edema
- Increased respiratory rate.

3-5.4.3 **Treatment of Near Drowning.**

- Assess airway, breathing, and circulation.
- Rescue breathing should be started as soon as possible, even before the victim is removed from the water.
- Give 100 percent oxygen by mask.
- Call for assistance from qualified medical personnel and transport to nearest medical facility for evaluation.

Victims of near drowning who have no neurological symptoms should be evaluated by a Diving Medical Officer for pulmonary aspiration. Pneumonia is the classic result of near drowning.

3-5.4.4 **Prevention of Near Drowning.** Drowning is best prevented by thoroughly training divers in safe diving practices and carefully selecting 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.

3-5.5 **Breathholding and Unconsciousness.** Most people can hold their breath approximately 1 minute, but usually not much longer without training or special preparation. At some time during a breathholding attempt, the desire to breathe becomes uncontrollable. The demand to breathe is signaled by the respiratory center responding to the increasing levels of carbon dioxide in the arterial blood and peripheral chemoreceptors responding to the corresponding fall in arterial oxygen partial pressure. If the breathhold is preceded by a period of voluntary hyperventilation, the breathhold can be much longer. Voluntary hyperventilation lowers body stores of carbon dioxide below normal (a condition known as hypocapnia), without significantly increasing oxygen stores. During the breathhold, it takes an appreciable time for the body stores of carbon dioxide to return to the normal level then to rise to the point where breathing is stimulated. During this time the oxygen partial pressure may fall below the level necessary to maintain consciousness. This is a common cause of breathholding accidents in swimming pools. Extended breathholding after hyperventilation is not a safe procedure.

WARNING **Voluntary hyperventilation is dangerous and can lead to unconsciousness and death during breathhold dives.**

Another hazard of breathhold diving is the possible loss of consciousness from hypoxia during ascent. Air in the lungs is compressed during descent, 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 0.10 ata (10% sev), unconsciousness may result. This danger is further heightened when hyperventilation has eliminated normal body warning signs of carbon dioxide accumulation and allowed the diver to remain on the bottom for a longer period of time. Refer to Chapter 6 for breathhold diving restrictions.

3-5.6 **Involuntary Hyperventilation.** Hyperventilation is the term applied to breathing more than is necessary to keep the body's carbon dioxide tensions at proper level. Hyperventiation may be voluntary (for example, to increase breathholding time) or involuntary. In involuntary hyperventilation, the diver is either unaware that he is breathing excessively, or is unable to control his breathing.

3-5.6.1 **Causes of Involuntary Hyperventilation.** Involuntary hyperventilation can be triggered by fear experienced during stressful situations. It can also be initiated by the slight "smothering sensation" that accompanies an increase in equipment dead space, an increase in static lung loading, or an increase in 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.

3-5.6.2 **Symptoms of Involuntary Hyperventilation.** Hyperventilation may lead to a biochemical imbalance that gives rise to dizziness, tingling of the extremities, and spasm of the small muscles of the hands and feet. Hyperventilating over a long period, produces additional symptoms such as weakness, headaches, numbness, faintness, and blurring of vision. The diver may experience a sensation of "air hunger" even though his ventilation is more than enough to eliminate carbon dioxide. All these symptoms can be easily confused with symptoms of CNS oxygen toxicity.

3-5.6.3 **Treatment of Involuntary Hyperventilation.** Hyperventilation victims should be encouraged to relax and slow their breathing rates. The body will correct hyperventilation naturally.

3-5.7 **Overbreathing the Rig.** "Overbreathing the Rig" is a special term divers apply to an episode of acute hypercapnia that develops when a diver works at a level greater than his UBA can support. When a diver starts work, or abruptly increases his workload, the increase in respiratory minute ventilation lags the increase in oxygen consumption and carbon dioxide production by several minutes. When the RMV demand for that workload finally catches up, the UBA may not be able to supply the gas necessary despite extreme respiratory efforts on the part of the diver. Acute hypercapnia with marked respiratory distress ensues. Even if the diver stops work to lower the production of carbon dioxide, the sensation of shortness of breath may persist or even increase for a short period of time. When this occurs, the inexperienced diver may panic and begin to hyperventilate. The situation can rapidly develop into a malicious cycle of severe shortness of breath and uncontrollable hyperventilation. In this situation, if even a small amount of water is inhaled, it can cause a spasm of the muscles of the larynx (voice box), called a laryngospasm, followed by asphyxia and possible drowning.

The U.S. Navy makes every effort to ensure that UBA meet adequate breathing standards to minimize flow resistance and static lung loading problems. However, all UBA have their limitations and divers must have sufficient experience to recognize those limitations and pace their work accordingly. Always increase workloads gradually to insure that the UBA can match the demand for increased lung ventilation. If excessive breathing resistance is encountered, slow or stop the pace of work until a respiratory comfort level is achieved. If respiratory distress occurs following an abrupt increase in workload, stop work and take even controlled breaths until the sensation of respiratory distress subsides. If the situation does not improve, abort the dive.

3-5.8 **Carbon Monoxide Poisoning.** The body produces carbon monoxide as a part of the process of normal metabolism. Consequently, there is always a small amount of carbon monoxide present in the blood and tissues. Carbon monoxide poisoning occurs when levels of carbon monoxide in the blood and tissues rise above these normal values due to the presence of carbon monoxide in the diver's gas supply. Carbon monoxide not only blocks hemoglobin's ability to delivery oxygen to the cells, causing cellular hypoxia, but also poisons cellular metabolism directly.

3-5.8.1 **Causes of Carbon Monoxide Poisoning.** Carbon monoxide is not found in any significant quantity in fresh air. Carbon monoxide poisoning is usually caused by a compressor’s intake being too close to the exhaust of an internal combustion engine or malfunction of a oil lubricated compressor. Concentrations as low as 0.002 ata (2,000 ppm, or 0.2%) can prove fatal.

3-5.8.2 **Symptoms of Carbon Monoxide Poisoning.** The symptoms of carbon monoxide poisoning are almost identical to those of hypoxia. When toxicity develops gradually the symptoms are:

- Headache
- Dizziness

- Confusion
- Nausea
- Vomiting
- Tightness across the forehead

When carbon monoxide concentrations are high enough to cause rapid onset of poisoning, the victim may not be aware of any symptoms before he becomes unconscious.

Carbon monoxide poisoning is particularly treacherous because conspicuous symptoms may be delayed until the diver begins to ascend. While at depth, the greater partial pressure of oxygen in the breathing supply forces 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, however, as the partial pressure of oxygen diminishes, the full effect of carbon monoxide poisoning is felt.

3-5.8.3 **Treatment of Carbon Monoxide Poisoning.** The immediate treatment of carbon monoxide poisoning consists of getting the diver to fresh air and seeking medical attention. Oxygen, if available, shall 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. Divers with severe symptoms (i.e. severe headache, mental status changes, any neurological symptoms, rapid heart rate) should be treated using Treatment Table 6.

3-5.8.4 **Prevention of Carbon Monoxide Poisoning.** Locating compressor intakes away from engine exhausts and maintaining air compressors in the best possible mechanical condition can prevent carbon monoxide poisoning. When carbon monoxide poisoning is suspected, isolate the suspect breathing gas source, and forward gas samples for analysis as soon as possible.

3-6 MECHANICAL EFFECTS OF PRESSURE ON THE HUMAN BODY-BAROTRAUMA DURING DESCENT

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. Barotrauma on descent is called squeeze. Barotrauma on ascent is called reverse squeeze.

3-6.1 Prerequisites for Squeeze.

For squeeze to occur during descent the following five conditions must be met:

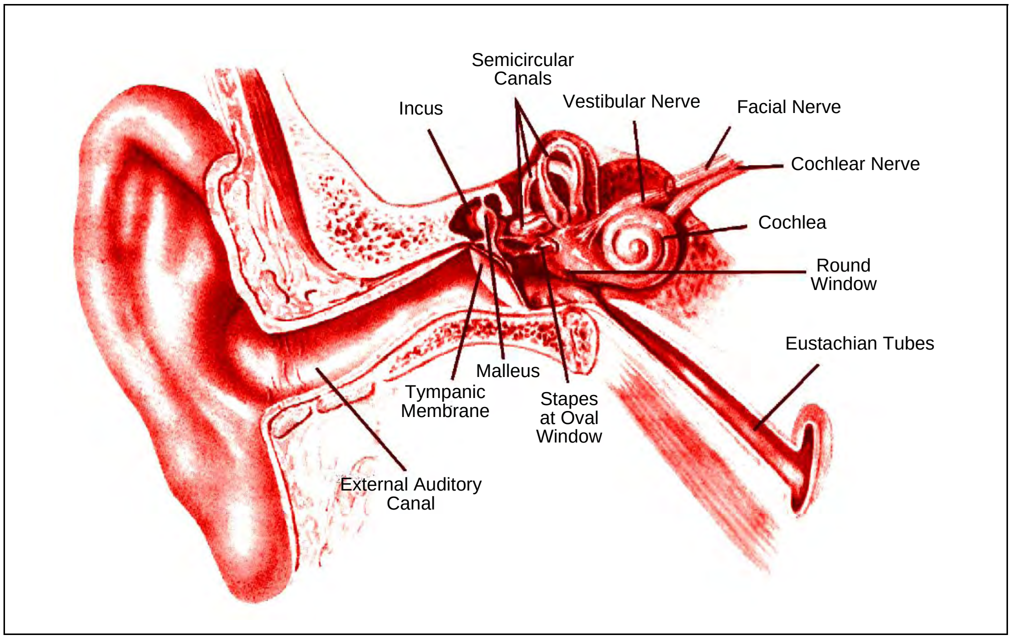

Figure 3-7. Gross Anatomy of the Ear in Frontal Section.

- There must be a gas-filled space. Any gas-filled space within the body (such as a sinus cavity) or next to the body (such as a face mask) can damage the body tissues when the gas volume changes because of increased pressure.

- The gas-filled space must have rigid walls. If the walls are collapsable like a balloon, no damage will be done by compression.

- The gas-filled space must be enclosed. If gas or liquid can freely enter the space as the gas volume changes, no damage will occur.

- The space must have lining membrane with an arterial blood supply and venous drainage that penetrates the space from the outside.. This allows blood to be forced into the space to compensate for the change in pressure.

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

3-6.2 **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 increases on the external surface of the drum. 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 that 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 bows inward and initially equalizes 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 ruptures, allowing air or water to enter the middle ear and equalize the pressure, or blood vessels rupture and cause sufficient bleeding into the middle ear to equalize the pressure. The latter usually happens.

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. When rupture occurs, this pain will diminish rapidly. Unless the diver is in hard hat diving dress, the middle ear cavity may be exposed to water when the ear drum ruptures. This exposes the diver to a possible middle ear infection and, in any case, prevents the diver from diving until the damage is healed. If eardrum rupture occurs, the dive shall be aborted. 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 malleus, 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 quickly pass when the water reaching the middle ear is warmed by the body. Suspected cases of eardrum rupture shall be referred to medical personnel.

3-6.2.1 **Preventing Middle Ear Squeeze.** 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. Medical personnel shall examine divers who have trouble clearing their ears before diving. 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 collapses 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 clear 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 collapses 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. If clearing cannot be accomplished as described above, abort the dive.

WARNING **Never do a forceful Valsalva maneuver during descent. A forceful Valsalva maneuver can result in alternobaric vertigo or barotrauma to the inner ear (see below).**

WARNING **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.**

3-6.2.2 **Treating Middle Ear Squeeze.** Upon surfacing after a middle ear squeeze, the diver may complain of pain, fullness in the ear, hearing loss, or even mild vertigo. Occasionally, the diver may have a bloody nose, the result of blood being forced out of the middle ear space and into the nasal cavity through the eustachian tube by expanding air in the middle ear. The diver shall report symptoms of middle ear squeeze to the diving supervisor and seek medical attention. Treatment consists of taking decongestants, pain medication if needed, and cessation of diving until the damage is healed. If the eardrum has ruptured antibiotics may be prescribed as well. Never administer medications directly into the external ear canal if a ruptured eardrum is suspected or confirmed unless done in direct consultation with an ear, nose, and throat (ENT) medical specialist.

3-6.3 **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 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 is very much like that described for the middle ear.

3-6.3.1 **Causes of Sinus Squeeze.** 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 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. 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.

3-6.3.2 **Preventing Sinus Squeeze.** 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.

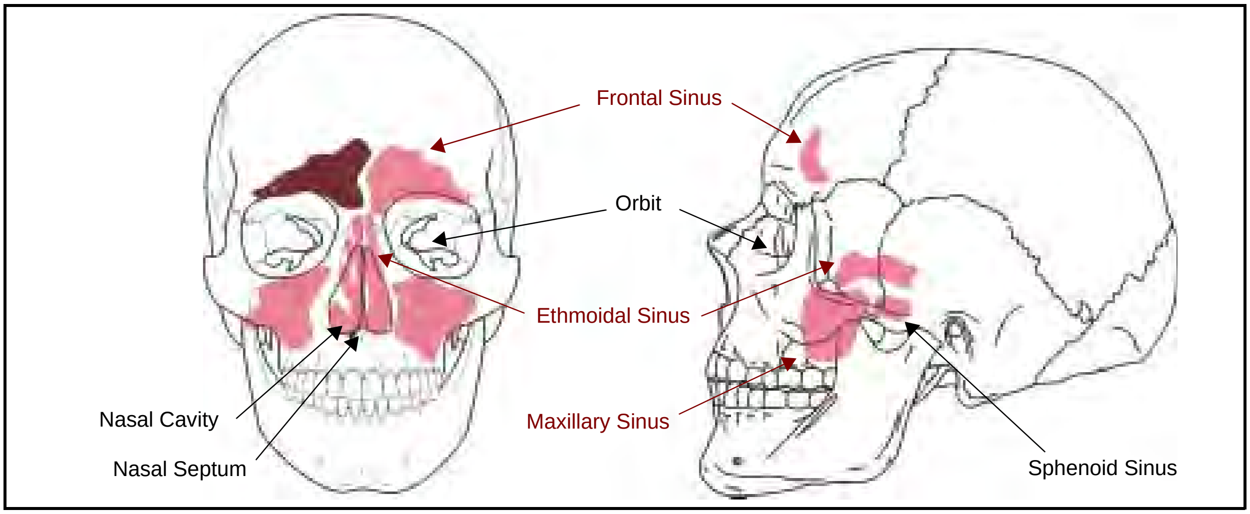

Figure 3-8. Location of the Sinuses in the Human Skull.

3-6.4 **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.

3-6.5 **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.

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.

3-6.6 **Thoracic (Lung) Squeeze.** When making a breathhold dive, it is possible to reach a depth at which the air held in the lungs is 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 is unable to compress the chest walls, force additional blood into the blood vessels in the chest, or elevate the diaphragm further. The pressure in the lung becomes negative with respect to the external water pressure. Injury takes the form of squeeze. Blood and tissue fluids are 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.

3-6.7 Face or Body Squeeze. SCUBA face masks, goggles, and certain types of exposure suits may cause squeeze under some conditions. Exhaling through the nose can usually equalize the pressure in a face mask, 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.

3-6.8 Inner Ear Barotrauma. The inner ear contains no gas and therefore cannot be “squeezed” in the same sense that the middle ear and sinuses can. However, the inner ear is located next to the middle ear cavity and is affected by the same conditions that lead to middle ear squeeze. To understand how the inner ear could be damaged as a result of pressure imbalances in the middle ear, it is first necessary to understand the anatomy of the middle and inner ear.

The inner ear contains two important organs, the cochlea and the vestibular apparatus. The cochlea is the hearing sense organ; damage to the cochlea will result in hearing loss and ringing in the ear (tinnitus). The vestibular apparatus is the balance organ; damage to the vestibular apparatus will result in vertigo and unsteadiness.

There are three bones in the middle ear: the malleus, the incus, and the stapes. They are also 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. When the stapes drives the oval window inward, the round window bulges outward to compensate. The fluid-filled spaces of the inner ear are also connected to the fluid spaces surrounding the brain by a narrow passage called the cochlear aqueduct. The cochlear aqueduct can transmit increases in cerebrospinal fluid pressure to the inner ear. When Valsalva maneuvers are performed to equalize middle ear and sinus pressure, cerebrospinal fluid pressure increases.

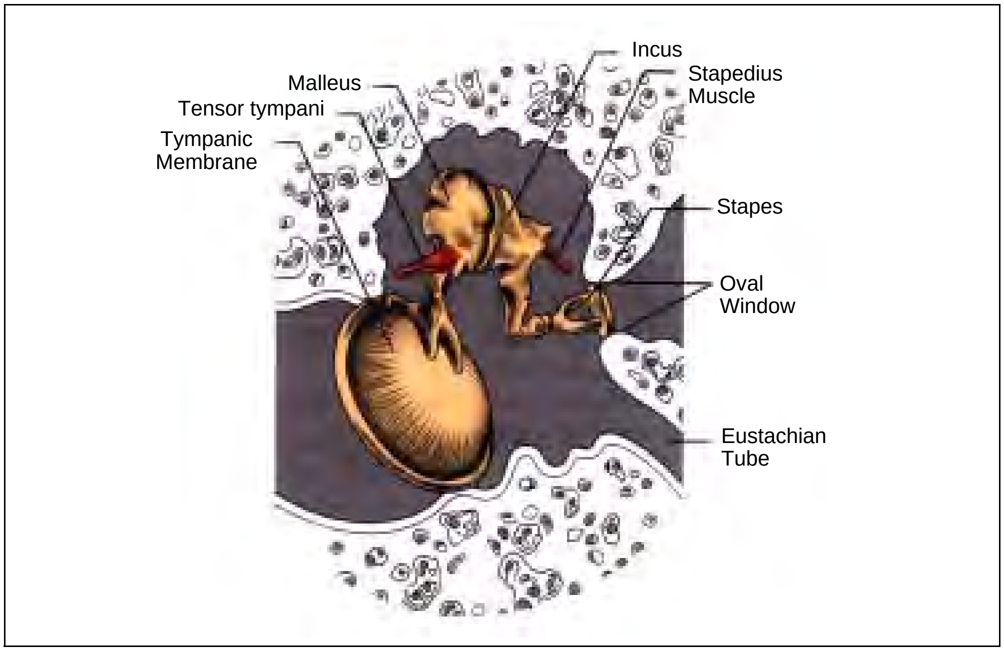

Figure 3-9. Components of the middle/inner ear

If middle ear pressure is not equalized during descent, the inward bulge of the eardrum is transmitted to the oval window by the middle ear bones. The stapes pushes the oval window inward. Because the inner ear fluids are incompressible, the round window correspondingly bulges outward into the middle ear space. If this condition continues, the round window may rupture spilling inner ear fluids into the middle ear and leading to a condition know as *inner ear barotrauma with perilymph fistula*. Fistula is a medical term for a hole in a membrane; the fluid in the inner ear is called perilymph. Rupture of the oval or round windows may also occur when middle ear pressures are suddenly and forcibly equalized. When equalization is sudden and forceful, the eardrum moves rapidly from a position of bulging inward maximally to bulging outward maximally. The positions of the oval and round windows are suddenly reversed Inner ear pressure is also increased by transmission of the Valsalva-induced increase in cerebrospinal fluid pressure. This puts additional stresses on these two membranes. Either the round or oval window may rupture. Rupture of the round window is by far the most common. The oval window is a tougher membrane and is protected by the foot-plate of the stapes. Even if rupture of the round or oval window does not occur, the pressure waves induced in the inner ear during these window movements may lead to disruption of the delicate cells involved in hearing and balance. This condition is referred to *inner ear barotrauma without perilymph fistula*.

The primary symptoms of inner ear barotrauma are persistent vertigo and hearing loss. Vertigo is the false sensation of motion. The diver feels that he is moving with respect to his environment or that the environment is moving with respect to him, when in fact no motion is taking place. The vertigo of inner ear barotrauma is generally described as whirling, spinning, rotating, tilting, rocking, or undulating. This sensation is quite distinct from the more vague complaints of dizziness or lightheadedness caused by other conditions. The vertigo of inner ear barotrauma is often accompanied by symptoms that may or may not be noticed depending on the severity of the insult. These include nausea, vomiting, loss of balance, incoordination, and a rapid jerking movement of the eyes, called nystagmus. Vertigo may be accentuated when the head is placed in certain positions. The hearing loss of inner ear barotrauma may fluctuate in intensity and sounds may be distorted. Hearing loss is accompanied by ringing or roaring in the affected ear. The diver may also complain of a sensation of bubbling in the affected ear.

Symptoms of inner ear barotrauma usually appear abruptly during descent, often as the diver arrives on the bottom and performs his last equalization manuever. However, the damage done by descent may not become apparent until the dive is over. A common scenario is for the diver to rupture a damaged round window while lifting heavy weights or having a bowel movement post dive. Both these activities increase cererbospinal fluid pressure and this pressure increase is transmitted to the inner ear. The round window membrane, weakened by the trauma suffered during descent, bulges into the middle ear space under the influence of the increased cerebrospinal fluid pressure and ruptures.

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 with head elevation to exploratory surgery, depending on the severity of the symptoms and whether a perilymph fistula is suspected. Any hearing loss or vertigo occurring within 72 hours of a hyperbaric exposure should be evaluated as a possible case of inner ear barotrauma.

When either hearing loss or vertigo develop after the diver has surfaced, it may be impossible to tell whether the symptoms are caused by inner ear barotrauma, decompression sickness or arterial gas embolism. For the latter two conditions, recompression treatement is mandatory. Although it might be expected that recompression treatment would further damage to the inner ear in a case of barotrauma and should be avoided, experience has shown that recompression is generally not harmful provided a few simple precautions are followed. The diver should be placed in a head up position and compressed slowly to allow adequate time for middle ear equalization. Clearing maneuvers should be gentle. The diver should not be exposed to excessive positive or negative pressure when breathing oxygen on the built-in breathing system (BIBS) mask. Always recompress the diver if there is any doubt about the cause of post-dive hearing loss or vertigo.

CAUTION **When in doubt, always recompress.**

Frequent oscillations in middle ear pressure associated with difficult clearing may lead to a transient vertigo. This condition is called *alternobaric vertigo of descent.* Vertigo usually follows a Valsalva maneuver, often with the final clearing episode just as the diver reaches the bottom. Symptoms typically last less than a minute but can cause significant disoriention during that period. Descent should be halted until the vertigo resolves. Once the vertigo resolves, the dive may be continued.

Alternobaric vertigo is a mild form of inner ear barotrauma in which no lasting damage to the inner ear occurs.

3-7 MECHANICAL EFFECTS OF PRESSURE ON THE HUMAN BODY--BAROTRAUMA DURING ASCENT

During ascent gases expand according to Boyle's Law. If the excess gas is not vented from enclosed spaces, damage to those spaces may result.

3-7.1 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. If rupture occurs, the middle ear will equalize pressure with the surrounding water and the pain will disappear. However, there may be a transient episode of intense vertigo as cold water enters the middle ear space.

The increased pressure in the middle ear may also affect the inner ear balance mechanism, leading to a condition called *alternobaric vertigo of ascent*. Alternobaric vertigo occurs when the middle ear space on one side is overpressurized while the other side is equalizing normally. The onset of vertigo is ususally sudden and may be preceded by pain in the ear that is not venting excess pressure. Alternobaric vertigo usually lasts for only a few minutes, but may be incapacitating during that time. Relief is usually abrupt and may be accompanied by a hissing sound in the affected ear as it equalizes. Alternobaric vertigo during ascent will disappear immediately if the diver halts his ascent and descends a few feet.

Increased pressure in the middle ear can also produce paralysis of the facial muscles, a condition known as *facial baroparesis*. In some individuals, the facial nerve is exposed to middle ear pressure as it traverses the temporal bone. If the middle ear fails to vent during ascent, the overpressure can shut off the blood supply to the nerve causing it to stop transmitting neual impulses to the facial muscles on the affected side. Generally, a 10 to 30 min period of overpressure is necessary for symptoms to occur. Full function of the facial muscles returns 5-10 min after the overpressure is relieved.

Increased pressure in the middle ear can also cause structural damage to the inner ear, a condition known as *inner ear barotrauma of ascent*. The bulging ear drum pulls the oval window outward into the middle ear space through the action of the middle ear bones. The round window correspondingly bulges inward. This inward deflection can be enhanced if the diver further increases middle ear pressure by performing a Valsalva maneuver. The round window may rupture causing inner ear fluids to spill into the middle ear space. The symptoms of marked hearing loss and sustained vertigo are identical to the symptoms experienced with inner ear barotrauma during descent.

A diver who has a cold or is unable to equalize the ears is more likely to develop reverse middle ear squeeze. There is no uniformly effective way to clear the ears on ascent. Do not perform a Valsalva maneuver 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 or vertigo 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. If symptoms of sustained hearing loss or vertigo appear during ascent, or shortly after ascent, it may be impossible to tell whether the symptoms are arising from inner ear barotrauma or from decompression sickness or arterial gas embolism. Recompression therapy is always indicated unless there is 100% certainty that the condition is inner ear barotrauma.

3-7.2 **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 is usually sufficient to stop the diver from ascending. Pain is immediately relieved by descending a few feet. From that point, the diver should titrate himself slowly to the surface in a series of ascents and descents just as with a reverse middle ear squeeze.

When overpressure occurs in the maxillary sinus, the blood supply to the infraorbital nerve may be reduced, leading to numbness of the lower eyelid, upper lip, side of the nose, and cheek on the affected side. This numbness will resolve spontaneously when the sinus overpressure is relieved.

3-7.3 **Gastrointestinal Distention.** Divers may occasionally experience abdominal pain during ascent because of gas expansion in the stomach or intestines. This condition is caused by gas being generated in the intestines during a dive, or by swallowing 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 to relieve the pain. 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. Abdominal pain following fast ascents shall be evaluated by a Diving Medical Officer.

To avoid intestinal gas expansion:

- Do not dive with an upset stomach or bowel.
- Avoid eating foods that are likely to produce intestinal gas.
- Avoid a steep, head-down angle during descent to minimize the amount of air swallowed.

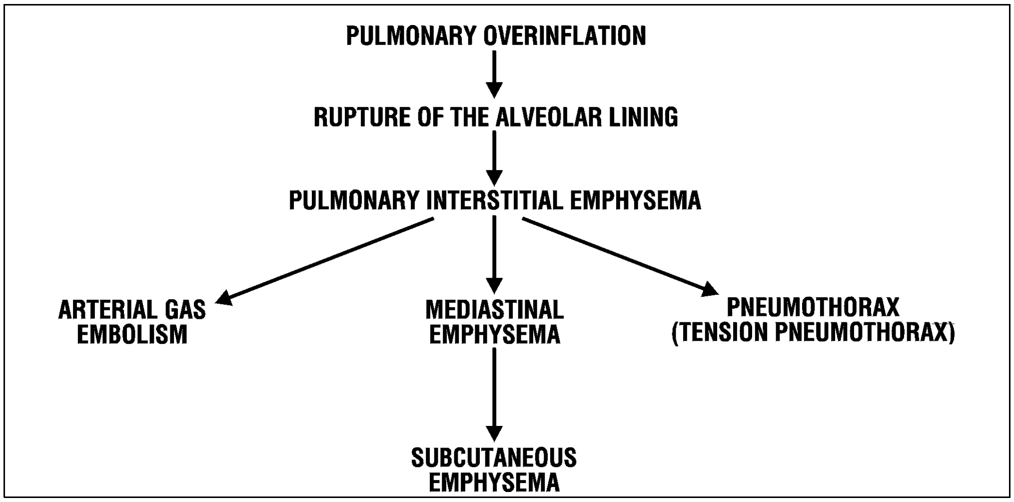

Figure 3-10. Pulmonary Overinflation Syndromes (POIS). Leaking of gas into the pulmonary interstitial tissue causes no symptoms unless further leaking occurs. If gas enters the arterial circulation, potentially fatal arterial gas embolism may occur. Pneumothorax occurs if gas accumulates between the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

3-8 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. Excess pressure inside the lung can also occur when a diver presses the purge button on a single-hose regulator while taking a breath. The two main causes of alveolar rupture are:

- Excessive pressure inside the lung caused by positive pressure
- Failure of expanding gas to escape from the lung during ascent

Pulmonary overinflation from expanding gas failing to escape from the lung during ascent can occur when a diver voluntarily or involuntarily holds his breath during ascent. Localized pulmonary obstructions that can cause air trapping, such as asthma or 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 where 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 conditions are depicted in Figure 3-10.

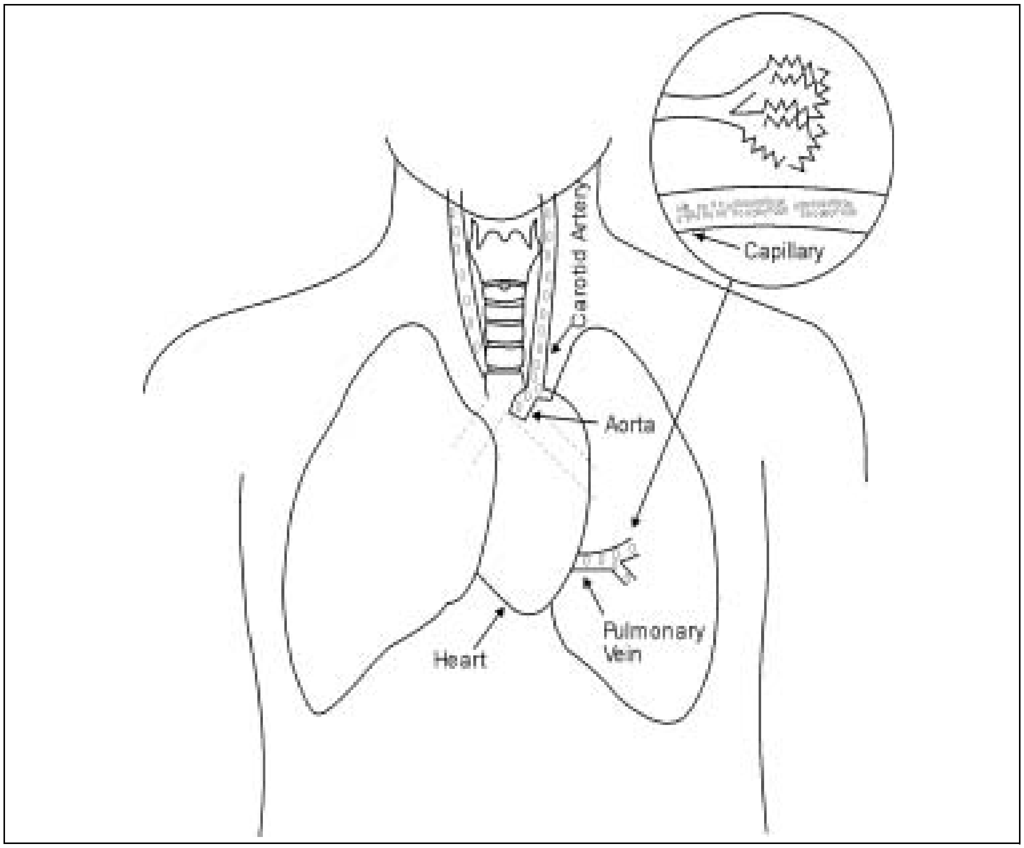

Figure 3-11. Arterial Gas Embolism

3-8.1 **Arterial Gas Embolism (AGE).** Arterial gas embolism (AGE), sometimes simply called gas embolism, is an obstruction of blood flow caused by gas bubbles (emboli) entering the arterial circulation. Obstruction of the arteries of the brain and heart can lead to death if not promptly relieved (see Figure 3-11).

3-8.1.1 **Causes of AGE.** AGE is 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 that 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 that are especially susceptible to arterial gas embolism and that are responsible for the life-threatening symptoms are the central nervous system (CNS) and the heart. In all cases of arterial gas embolism, associated pneumothorax is possible and should not be overlooked. Exhaustion of air supply and the need for an emergency ascent is the most common cause of AGE.

3-8.1.2 Symptoms of AGE.

- Unconsciousness
- Paralysis
- Numbness
- Weakness
- Extreme fatigue
- Large areas of abnormal sensations (Paresthesias)
- Difficulty in thinking
- Vertigo
- Convulsions
- Vision abnormalities
- Loss of coordination
- Nausea and or vomiting
- Hearing abnormalities
- Sensation similar to that of a blow to the chest during ascent.
- Bloody sputum
- Dizziness
- Personality changes
- Loss of control of bodily functions
- Tremors

Symptoms of subcutaneous / medistinal emphysema, pneumothorax and/or pneumopericardium may also be present (see below). In all cases of arterial gas embolism, the possible presence of these associated conditions should not be overlooked.

3-8.1.3 Treatment of AGE.

- Basic first aid (ABC)
- 100 percent oxygen

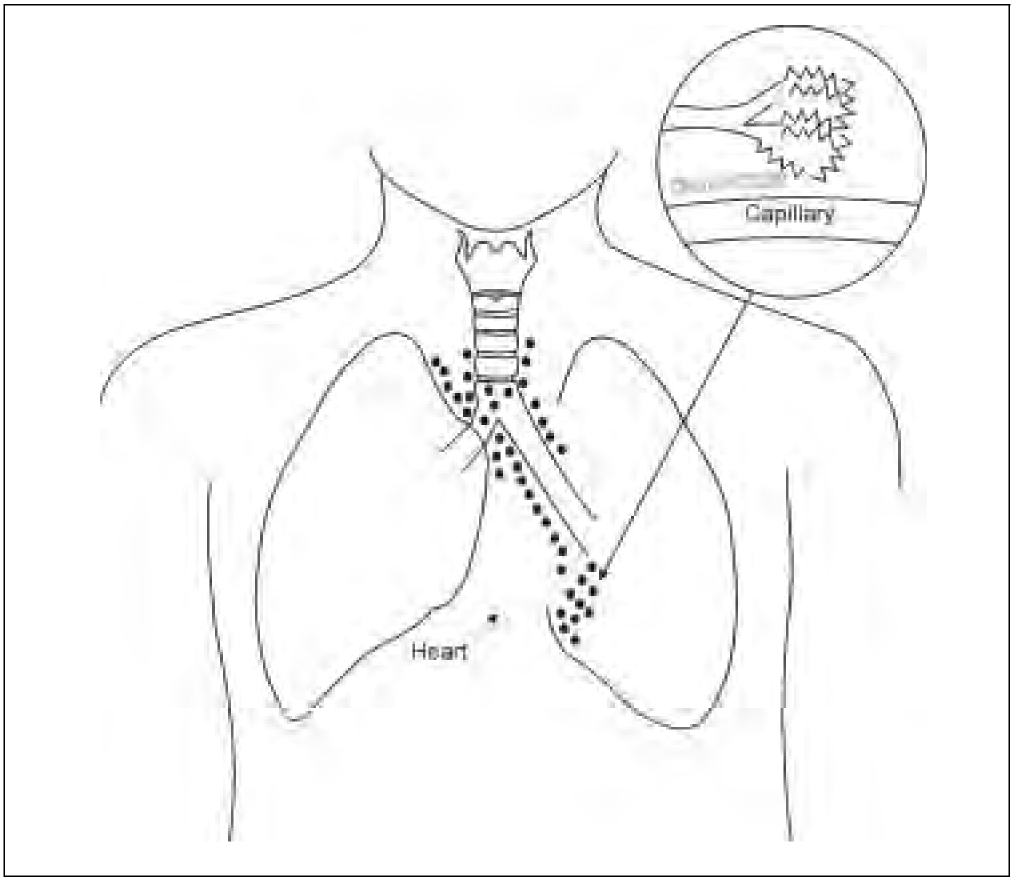

Figure 3-12. Mediastinal Emphysema

- Immediate recompression
- See Volume 5 for more specific information regarding treatment.

3-8.1.4 Prevention of AGE.

The risk of arterial gas embolism can be substantially reduced or eliminated by paying careful attention to the following:

- Every diver must receive intensive training in diving physics and physiology, as well as instruction in the correct use of diving equipment. Particular attention must be given to the training of SCUBA divers, because SCUBA operations produce a comparatively high incidence of embolism accidents.
- A diver must never interrupt breathing during ascent from a dive in which compressed gas has been breathed.

- A diver must exhale continuously while making an emergency ascent. 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 postive buoyancy is lost. In a uncontrolled or buoyant ascent, where a life preserver, dry suit or buoyancy compensator assists the diver, 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, and forceful. 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.

NOTE **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.**

- The diver must not hesitate to report any illness, especially respiratory illness such as a cold, to the Diving Supervisor or Diving Medical Personnel prior to diving.

3-8.2 **Mediastinal and Subcutaneous Emphysema.** Mediastinal emphysema, also called pneumomediastinum, occurs when gas is forced through torn lung tissue into the loose mediastinal tissues in the middle of the chest surrounding the heart, the trachea, and the major blood vessels (see Figure 3-12). Subcutaneous emphysema occurs when that gas subsequently migrates into the subcutaneous tissues of the neck (Figure 3-13). Mediastinal emphysema is a pre-requisite for subcutaneous emphysema.

3-8.2.1 **Causes of Mediastinal and Subcutaneous Emphysema.** Mediastinal/subcutaneous emphysema is caused by over inflation of the whole lung or parts of the lung due to:

- Breath holding during ascent
- Positive pressure breathing such as ditch and don exercises
- Drown proofing exercises
- Cough during surface swimming

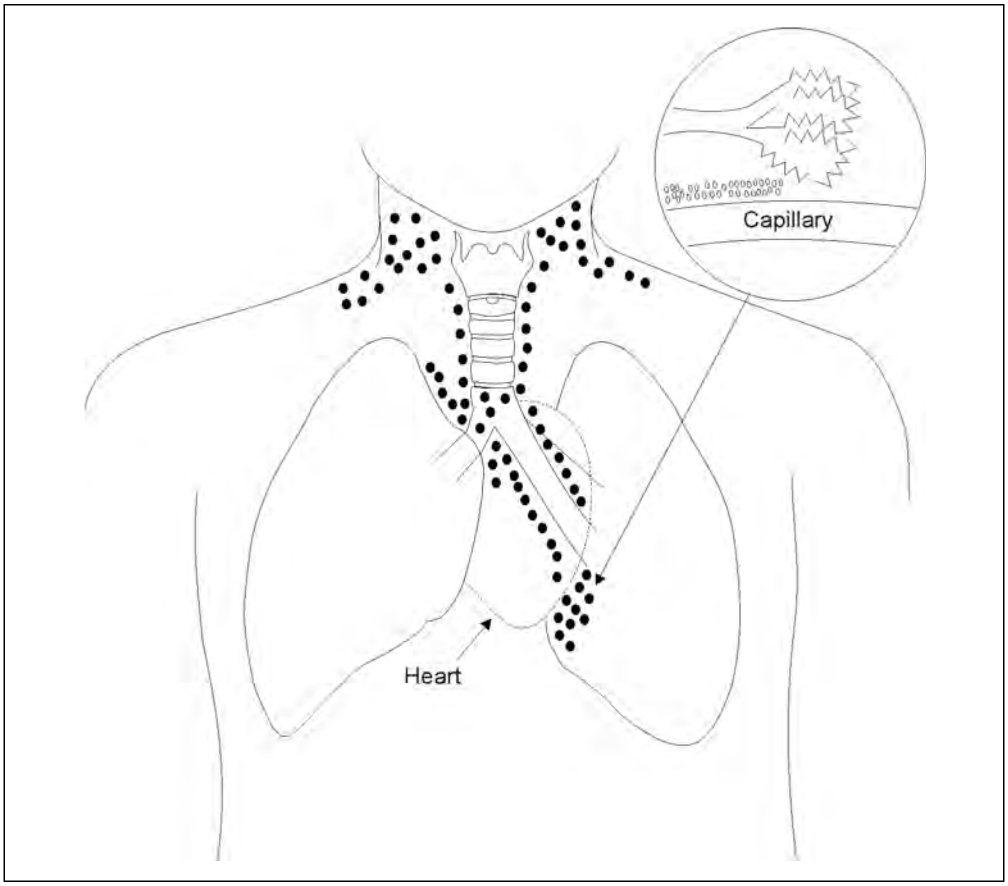

Figure 3-13. Subcutaneous Emphysema

3-8.2.2 **Symptoms of Medistinal and Subcutaneous Emphysema.** Mild cases are often unnoticed by the diver. In more severe cases, the diver may experience mild to moderate pain under the breastbone, often described as dull ache or feeling of tightness. The pain may radiate to the shoulder or back and may increase upon deep inspiration, coughing, or swallowing. The diver may have a feeling of fullness around the neck and may have difficulty in swallowing. His voice may change in pitch. An observer may note a swelling or apparent inflation of the diver's neck. Movement of the skin near the windpipe or about the collar bone may produce a cracking or crunching sound (crepitation).

3-8.2.3 **Treatment of Mediastinal and Subcutaneous Emphysema.** Suspicion of mediastinal or subcutaneous emphysema warrants prompt referral to medical personnel to rule out the coexistence of arterial gas embolism or pneumothorax. The latter two conditions require more aggressive treatment. 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 5 or 10 feet). An hour of breathing oxygen should be sufficient for resolution, but longer stays may be necessary.

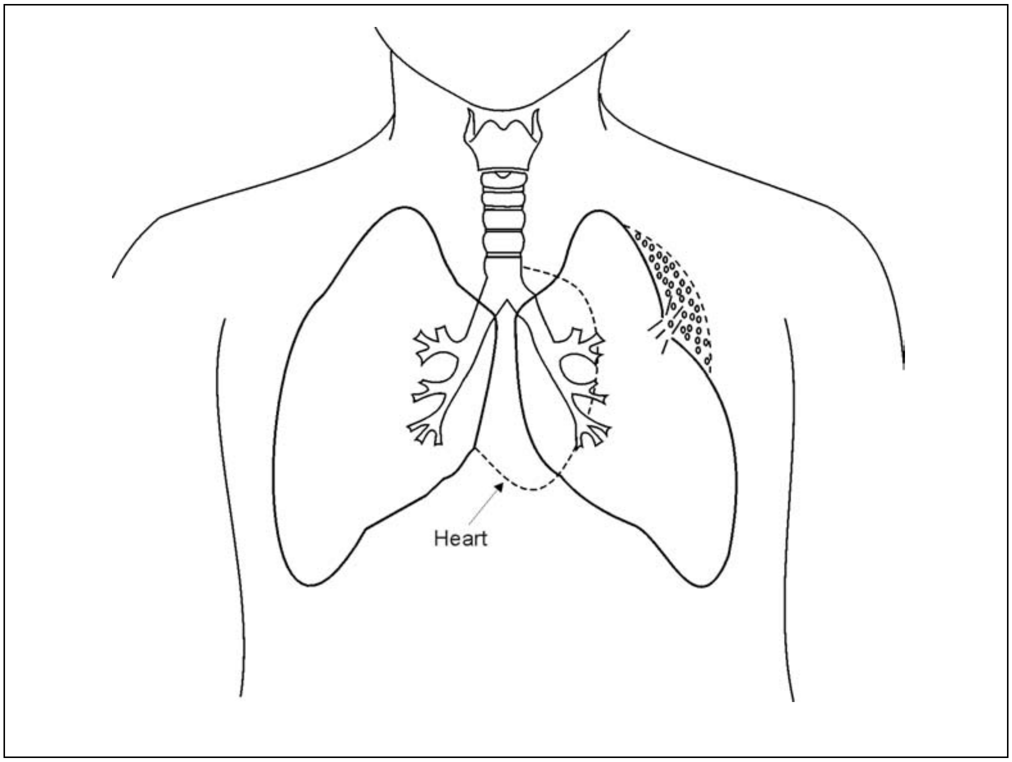

Figure 3-14. Pneumothorax.

Decompression will be dictated by the tender's decompression obligation. The appropriate air table should be used, but the ascent rate should not exceed 1 foot per minute. In this specific case, the delay in ascent should be included in bottom time when choosing the proper decompression table.

3-8.2.4 Prevention of Mediastinal and Subcutaneous Emphysema. The strategies for preventing mediastinal/subcutaneous emphysema are identical to the strategies for preventing arterial gas embolism. Breathe normally during ascent. If emergency ascent is required, exhale continuously. Mediastinal/subcutaneous emphysema is particularly common after ditch and don exercises. Avoid positive pressure breathing situations during such exercises. The mediastinal/subcutaneous emphysema that is seen during drown proofing exercises and during surface swimming unfortunately is largely unavoidable.

3-8.3 Pneumothorax. A pneumothorax is air trapped in the pleural space between the lung and the chest wall (Figure 3-14).

3-8.3.1 Causes of Pneumothorax. A pneumothorax occurs when the lung surface ruptures and air spills into the space between the lung and chest wall. Lung rupture can result from a severe blow to the chest or from overpressurization of the lung. 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.

In certain instances, the damaged lung may allow air to enter but not exit the pleural space. Successive breathing gradually enlarges the air pocket. This is called a tension pneumothorax (Figure 3-15) because of the progressively increasing tension or pressure exerted on the lung and heart by the expanding gas. If uncorrected, this force presses 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 impairs both respiration and circulation.

A simple pneumothorax that occurs while the diver is at depth can be converted to a tension pneumothorax by expansion of the gas pocket during ascent. Although a ball valve like mechanism that allows air to enter the pleural cavity but not escape is not present, the result is the same. The mounting tension collapses the lung on the affected side and pushes the heart and lung to the opposite side of the chest.

3-8.3.2 **Symptoms of Pneumothorax.** The onset of a simple pneumothorax is accompanied by a sudden, sharp chest pain, followed by shortness of breath, labored breathing, rapid heart rate, a weak pulse, and anxiety. The normal chest movements associated with respiration may be reduced on the affected side and breath sounds may be difficult to hear with a stethoscope.

The symptoms of tension pneumothorax are similar to simple pneumothorax, but become progressively more intense over time. As the heart and lungs are displaced to the opposite side of the chest, blood pressure falls along with the arterial oxygen partial pressure. Cyanosis (a bluish discoloration) of the skin appears. If left untreated, shock and death will ensue. Tension pneumothorax is a true medical emergency.

3-8.3.3 **Treatment of Pneumothorax.** A diver believed to be suffering from pneumothorax must be thoroughly examined for the possible co-existence of arterial gas embolism. This is covered more fully in Volume 5.

A small pneumothorax (less than 15%) normally will improve with time as the air in the pleural space is reabsorbed spontaneously. A larger pneumothorax may require active treatment. Mild pneumothorax can be treated by breathing 100 percent oxygen. Cases of pneumothorax that demonstrate cardio-respiratory compromise may require the insertion of a chest tube, largebore intravenous (IV) catheter, or other device designed to remove intrathoracic gas (gas around the lung). Only personnel trained in the use of these and the other accessory devices (one-way valves, underwater suction, etc.) necessary to safety decompress the thoracic cavity should insert them. 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 with a one-way relief valve may need to be inserted at depth to prevent expansion of the trapped gas during subsequent ascent. A tension pneumothorax should always be suspected if the diver's condition deteriorates rapidly during ascent, especially if the symptoms are respiratory. If a tension pneumothorax is found, recompress to depth of relief until the thoracic cavity can be properly vented. Pneumothorax, if

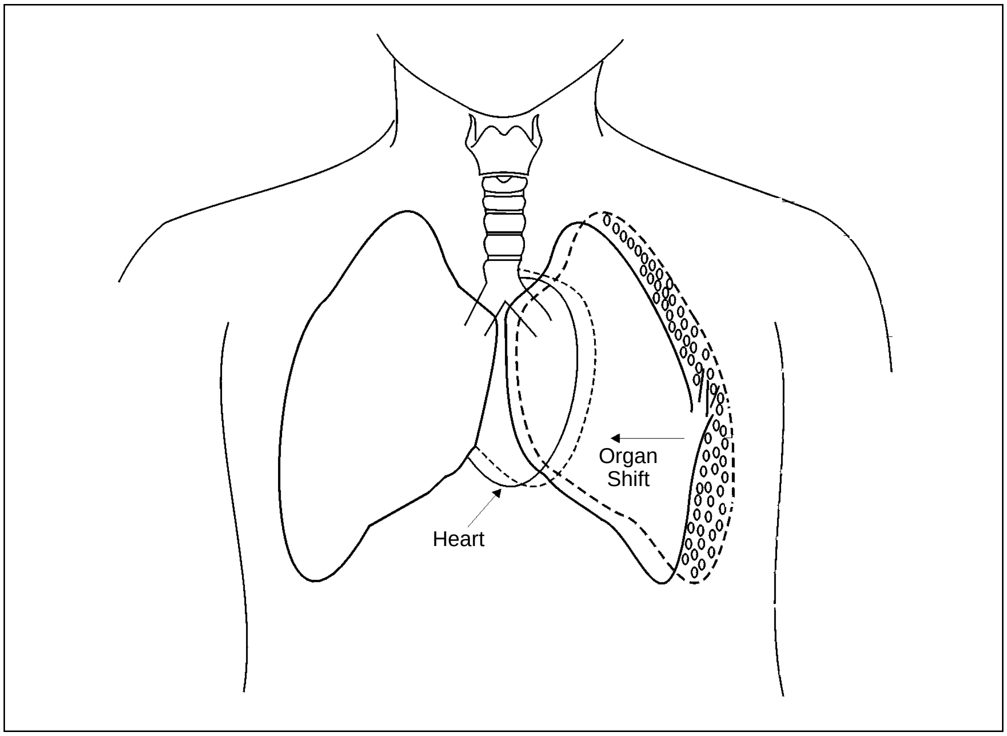

Figure 3-15. Tension Pneumothorax

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 before ascent from treatment depth. In cases of tension pneumothorax, this procedure may be lifesaving. Volume 5 fully discusses the treatment of simple and tension pneumothorax.

3-8.3.4 **Prevention of Pneumothorax.** The strategies for avoiding pneumothorax are the same as those for avoiding arterial gas embolism. Breathe normally during ascent. If forced to perform an emergency ascent, exhale continuously.

3-9 INDIRECT EFFECTS OF PRESSURE ON THE HUMAN BODY.

The conditions previously described occur because of differences in pressure that 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 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.

3-9.1 **Nitrogen Narcosis.** Nitrogen narcosis is the state of euphoria and exhilaration that occurs when a diver breathes a gas mixture with a nitrogen partial pressure greater than 4 ata.

3-9.1.1 **Causes of Nitrogen Narcosis.** Breathing nitrogen at high partial pressures has a narcotic effect on the central nervous system that causes euphoria and impairs the diver's ability to think clearly. The narcotic effect begins at a nitrogen partial pressure of approximately 4 ata and increases in severity as the partial pressure is increased beyond that point. A nitrogen partial pressure of 8 ata causes very marked impairment; partial pressures in excess of 10 ata may lead to hallucinations and unconsciousness. For an dive on air, narcosis usually appears at a depth of approximately 130 fsw, is very prominent at a depth of 200 fsw, and becomes disabling at deeper depths.

There is a wide range of individual susceptibility to narcosis. There is also some evidence that adaptation occurs on repeated exposures. Some divers, particularly those experienced in deep operations with air, can often work as deep as 200 fsw without serious difficulty. Others cannot.

3-9.1.2 **Symptoms of Nitrogen Narcosis.**

The symptoms of nitrogen narcosis include:

- Loss of judgment or skill
- A false feeling of well-being
- Lack of concern for job or safety
- Apparent stupidity
- Inappropriate laughter
- Tingling and vague numbness of the lips, gums, and legs

Disregard for personal safety is the greatest hazard of nitrogen narcosis. Divers may display abnormal behavior such as removing the regulator mouthpiece or swimming to unsafe depths without regard to decompression sickness or air supply.

3-9.1.3 **Treatment of Nitrogen narcosis.** The treatment for nitrogen narcosis is to bring the diver to a shallower depth where the effects are not felt. The narcotic effects will rapidly dissipate during the ascent. There is no hangover associated with nitrogen narcosis.

3-9.1.4 **Prevention of Nitrogen Narcosis.** 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 or dive with helium-oxygen mixtures.

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. Diving with helium-oxygen mixtures is the only way to prevent nitrogen narcosis. Helium-oxygen mixtures should be considered for any dive in excess of 150 fsw.

3-9.2 Oxygen Toxicity. Exposure to a partial pressure of oxygen above that encountered in normal daily living may be toxic to the body. The extent of the toxicity is dependent upon both the oxygen partial pressure and the exposure time. The higher the partial pressure and the longer the exposure, the more severe the toxicity. The two types of oxygen toxicity experienced by divers are pulmonary oxygen toxicity and central nervous system (CNS) oxygen toxicity.

3-9.2.1 Pulmonary Oxygen Toxicity. Pulmonary oxygen toxicity, sometimes called low pressure oxygen poisoning, can occur whenever the oxygen partial pressure exceeds 0.5 ata. A 12 hour exposure to a partial pressure of 1 ata will produce mild symptoms and measurable decreases in lung function. The same effect will occur with a 4 hour exposure at a partial pressure of 2 ata.

Long exposures to higher levels of oxygen, such as administered during Recompression Treatment Tables 4, 7, and 8, may produce 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 eventually limit further exposure to oxygen. Unconscious patients who receive oxygen treatments do 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 taken when administering 100 percent oxygen to unconscious patients even at surface pressure.

Return to normal pulmonary function gradually occurs after the exposure is terminated. There is no specific treatment for pulmonary oxygen toxicity.

The only way to avoid pulmonary oxygen toxicity completely is to avoid the long exposures to moderately elevated oxygen partial pressures that produce it. However, there is a way of extending tolerance. If the oxygen exposure is periodically interrupted by a short period of time at low oxygen partial pressure, the total exposure time needed to produce a given level of toxicity can be increased significantly. This is the basis for the "air breaks" commonly seen in both decompression and recompression treatment tables.

3-9.2.2 Central Nervous System (CNS) Oxygen Toxicity. Central nervous system (CNS) oxygen toxicity, sometimes called high pressure oxygen poisoning, can occur whenever the oxygen partial pressure exceeds 1.3 ata in a wet diver or 2.4 ata in a dry diver. The reason for the marked increase in susceptibility in a wet diver is not completely understood. At partial pressures above the respective 1.3 ata wet and 2.4 ata dry thresholds, the risk of CNS toxicity is dependent on the oxygen partial pressure and the exposure time. The higher the partial pressure and the longer the exposure time, the more likely CNS symptoms will occur. This gives rise to partial pressure of oxygen-exposure time limits for various types of diving.

3-9.2.2.1 ***Factors Affecting the Risk of CNS Oxygen Toxicity.*** A number of factors are known to influence the risk of CNS oxygen toxicity:

Individual Susceptibility. Susceptibility to CNS oxygen toxicity varies markedly from person to person. Individual susceptibility also varies markedly from time to time and for this reason divers may experience CNS oxygen toxicity at exposure times and pressures previously tolerated. Individual variability makes it difficult to set oxygen exposure limits that are both safe and practical.

CO_2 Retention. Hypercapnia greatly increases the risk of CNS toxicity probably through its effect on increasing brain blood flow and consequently brain oxygen levels. Hypercapnia may result from an accumulation of CO_2 in the inspired gas or from inadequate ventilation of the lungs. The latter is usually due to increased breathing resistance or a suppression of respiratory drive by high inspired ppO2. Hypercapnia is most likely to occur on deep dives and in divers using closed and semi-closed circuit rebreathers.

Exercise. Exercise greatly increases the risk of CNS toxicity, probably by increasing the degreee of CO_2 retention. Exposure limits must be much more conservative for exercising divers than for resting divers.

Immersion in Water. Immersion in water greatly increases the risk of CNS toxicity. The precise mechanism for the big increase in risk over comparable dry chamber exposures is unknown, but may involve a greater tendency for diver CO_2 retention during immersion. Exposure limits must be much more conservative for immersed divers than for dry divers.

Depth. Increasing depth is associated with an increased risk of CNS toxicity even though ppO_2 may remain unchanged. This is the situation with UBAs that control the oxygen partial pressure at a constant value, like the MK 16. The precise mechanism for this effect is unknown, but is probably more than just the increase in gas density and concomitant CO_2 retention. There is some evidence that the inert gas component of the gas mixture accelerates the formation of damaging oxygen free radicals. Exposure limits for mixed gas diving must be more conservative than for pure oxygen diving.

Intermittent Exposure. Periodic interruption of high ppO_2 exposure with a 5-15 min exposure to low ppO_2 will reduce the risk of CNS toxicity and extend the total allowable exposure time to high ppO_2. This technique is most often employed in hyperbaric treatments and surface decompression.

Because of these modifying influences, allowable oxygen exposure times vary from situation to situation and from diving system to diving system. In general, closed and semi-closed circuit rebreathing systems require the lowest partial pressure limits, whereas surface-supplied open-circuit systems permit slightly higher limits. Allowable oxygen exposure limits for each system are discussed in later chapters.

3-9.2.2.2 ***Symptoms of CNS Oxygen Toxicity.*** 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 also may be remembered by the mnemonic VENTIDC:

V: Visual symptoms: Tunnel vision, a decrease in diver's peripheral vision, and other symptoms, such as blurred vision, may occur.

E: Ear symptoms. Tinnitus, any sound perceived by the ears but not resulting from an external stimulus, may resemble bells ringing, roaring, or a machinery-like pulsing sound.

N: Nausea or spasmodic vomiting. These symptoms may be intermittent.

T: Twitching and tingling symptoms. Any of the small facial muscles, lips, or muscles of the extremities may be affected. These are the most frequent and clearest symptoms.

I: Irritability: Any change in the diver's mental status including confusion, agitation, and anxiety.

D: Dizziness. Symptoms include clumsiness, incoordination, and unusual fatigue.

C: Convulsions. The first sign of CNS oxygen toxicity may be convulsions that occur with little or no warning.

Warning symptoms may not always appear and most are not exclusively symptoms of oxygen toxicity. Muscle twitching is perhaps the clearest warning, but it may occur late, if at all. If any of these warning symptoms occur, the diver should take immediate action to lower the oxygen partial pressure.

A convulsion, 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 *postconvulsive (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 often becomes suddenly alert and complains of no more than fatigue, muscular soreness, and possibly a headache. After an oxygen-toxicity convulsion, the diver usually remembers clearly the events up to the moment when consciousness was lost, but remembers nothing of the convulsion itself and little of the postictal phase.

3-9.2.2.3 ***Treatment of CNS Oxygen Toxicity.*** A diver who experiences the warning symptoms of oxygen toxicity shall inform the Diving Supervisor immediately. The following actions can be taken to lower the oxygen partial pressure:

- Ascend
- Shift to a breathing mixture with a lower oxygen percentage
- In a recompression chamber, remove the mask.

WARNING **Reducing the oxygen partial pressure does not instantaneously reverse the biochemical changes in the central nervous system caused by high oxygen partial pressures. 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 2 or 3 minutes.**

Despite its rather alarming appearance, the convulsion itself is usually not much more than a strenuous muscular workout for the victim. 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 diver convulses, the UBA should be ventilated immediately with a gas of lower oxygen content, if possible. If depth control is possible and the gas supply is secure (helmet or full face mask), the diver should be kept at depth until the convulsion subsides and normal breathing resumes. If an ascent must take place, it should be done as slowly as possible to reduce the risk of an arterial gas embolism. A diver surfacing unconscious because of an oxygen convulsion must be treated as if suffering from arterial gas embolism. Arterial gas embolism cannot be ruled out in an unconscious diver.

If the convulsion occurs in a recompression chamber, it is important to keep the individual from thrashing against hard objects and being injured. Complete restraint of the individual’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. Management of CNS oxygen toxicity during recompression therapy is discussed fully in Volume 5.

If a convulsing diver is prevented from drowning or causing other injury to himself, full recovery with no lasting effects can be expected within 24 hours. Susceptibility to oxygen toxicity does not increase as a result of a convulsion, although divers may be more inclined to notice warning symptoms during subsequent exposures to oxygen.

3-9.2.2.4 ***Prevention of CNS Oxygen Toxicity.*** 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. Interruption of oxygen breathing with periodic "air" breaks can extend the exposure time to high oxygen partial pressures significantly. Air breaks are routinely incorporated into recompression treatment tables and some decompression tables.

3-9.3 Decompression Sickness (DCS). A diver's blood and tissues absorb additional nitrogen (or helium) from the lungs when at depth. If a diver ascends too fast this excess gas will separate from solution and form bubbles. These bubbles produce mechanical and biochemical effects that lead to a condition known as *decompression sickness*.

3-9.3.1 **Absorption and Elimination of Inert Gases.** The average human body at sea level contains about 1 liter of nitrogen. All of the body tissues are saturated with nitrogen at a partial pressure equal to the partial pressure in the alveoli, about 0.79 ata. If the partial pressure of nitrogen changes because of a change in the pressure or composition of the breathing mixture, the pressure of the nitrogen dissolved in the body gradually attains a matching level. Additional quantities of nitrogen are absorbed or eliminated, depending on the partial pressure gradient, until the partial pressure of the gas in the lungs and in the tissues is equal. If a diver breathes helium, a similar process occurs.

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

The process of taking up more inert gas is called absorption or saturation. The process of giving up inert gas is called elimination or desaturation. The chain of events is essentially the same in both processes even though the direction of exchange is opposite.

Shading in diagram (Figure 3-16) 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 than 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 through the body as a whole is far from saturation. If enough time elapses at depth, all tissues will become equally saturated, as shown in lower diagram.

3-9.3.1.1 ***Saturation of Tissues.*** The sequence of events in the process of saturation can be illustrated by considering what happens in the body of a diver taken rapidly from the surface to a depth of 100 fsw (Figure 3-16). To simplify matters, we can say that the partial pressure of nitrogen in his blood and tissues on leaving the surface is roughly 0.8 ata. When the diver reaches 100 fsw, the alveolar nitrogen pressure in his lungs will be about 0.8 × 4 ata = 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 minus 0.8, or 2.4 ata. This gradient is the driving force that makes the molecules of nitrogen move by diffusion from one place to another. Consider the following 10 events and factors in the diver at 100 fsw:

1. 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.
2. 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 that reaches a tissue over a short period of time loses its excess nitrogen to the tissue without greatly increasing the tissue nitrogen pressure.
3. 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.
4. When the blood returns to the tissue, it again loses nitrogen until a new equilibrium is reached.
5. 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.
6. 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.
7. All body tissues are composed of lean and fatty components. If a tissue has an unusually large capacity for nitrogen, it takes 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

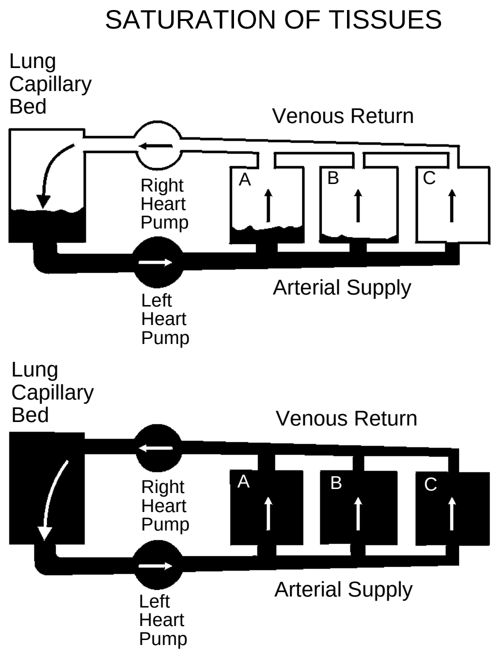

Figure 3-16. Saturation of Tissues. Shading in diagram indicates saturation with nitrogen or helium under increased pressure. Blood becomes saturated on passing through lungs, and tissues are saturated in turn via blood. Those with a large supply (as in A above) are saturated much more rapidly than those 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 through the body as a whole is far from saturation. If enough time elapses at depth, all tissues will become equally saturated, as shown in lower diagram.

require much more nitrogen and much more time to saturate them completely than lean (watery) tissues do, even if the blood supply is ample. Adipose tissue (fat) has a poor blood supply and therefore saturates very slowly.

8. At 100 fsw, 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, may not be completely saturated unless the diver is kept at 100 fsw for 72 hours or longer.

9. If kept at a depth of 100 fsw until saturation is complete, the diver's body contains about four times as much nitrogen as it did at the surface. Divers of average size and fatness have about one liter of dissolved nitrogen at the surface and about four liters at 100 fsw. Because fat holds about five times as much nitrogen as lean tissues, much of a diver's nitrogen content is in his fatty tissue.

10. An important fact about nitrogen saturation is that the process requires the same length of time regardless of the nitrogen pressure involved. For example, if the diver had been taken to 33 fsw 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 fsw, 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 become saturated with that gas in the same process as for nitrogen. However, the time required to reach saturation is different for each gas. This is because the blood and tissue solubilities are different for the different inert gases. Helium, for example, is much less soluble in fat than nitrogen is.

3-9.3.1.2 ***Desaturation of Tissues.*** The process of desaturation is the reverse of saturation (Figure 3-17). If the partial pressure of the inert gas in the lungs is reduced, either through a reduction in the diver's depth or a change in the breathing medium, the new pressure gradient induces 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 desaturate more slowly than others for the same reason that they saturate more slowly: poor blood supply or a greater capacity to store inert gas. Washout of excess inert gas from these "slow" tissues will lag behind washout from the faster tissues.

3-9.3.2 **Bubble Formation.** Inert gas may separate from physical solution and form bubbles if the partial pressure of the inert gas in blood and tissues exceeds the ambient pressure by more than a critical amount. During descent and while the diver is on the bottom, blood and tissue inert gas partial pressures increase significantly as tissue saturation takes place, but the inert gas pressure always remains less than the ambient pressure surrounding the diver. Bubbles cannot form in this situation. During ascent the converse is true. Blood and tissue inert gas pressures fall as the tissues desaturate, but blood and tissue inert gas pressures can exceed the ambient pressure if the rate of ascent is faster than the rate at which tissues can equilibrate. Consider an air diver fully saturated with nitrogen at a depth of 100 fsw. All body tissues have a nitrogen partial pressure of 3.2 ata.. If the diver were to quickly ascend to the surface, the ambient pressure surrounding his tissues would be reduced to 1 ata. Assuming that ascent was fast enough not to allow for any tissue desaturation, the nitrogen pressure in all the tissues would be 2.2 ata greater than the ambient pressure (3.2 ata - 1 ata). Under this circumstance bubbles can form.

Bubble formation can be avoided if the ascent is controlled in such a way that the tissue inert gas pressure never exceeds the ambient pressure by more than the critical amount. This critical amount, called the *allowable supersaturation*, varies from tissue to tissue and from one inert gas to another. A decompression table shows the time that must be spent at various decompression stops on the way to the surface to allow each tissue to desaturate to the point where its allowable supersaturation is not exceeded.

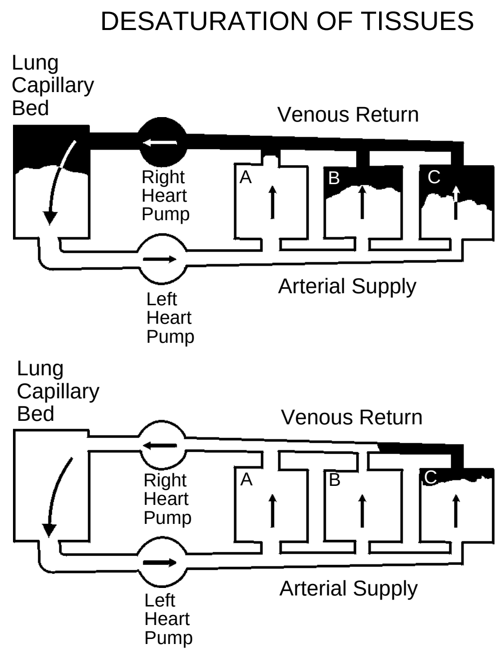

Figure 3-17. Desaturation of Tissues. The desaturation process is essentially the reverse of saturation. When pressure of inert gas is lowered, blood is cleared of excess gas as it goes through the lungs. Blood then removes gas from the tissues at rates depending on amount of blood that flows through them each minute. Tissues 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).

3-9.3.3 **Direct Bubble Effects.** Bubbles forming in the tissues (autochthonous bubbles) and in the bloodstream (circulating bubbles) may exert their effects directly in several ways:

- Autochthonous bubbles can put pressure on nerve endings, stretch and tear tissue leading to hemorrhage, and increase pressure in the tissue leading to slowing or cessation of incoming blood flow. These are thought to be the primary mechanisms for injury in Spinal Cord, Musculoskeletal, and Inner Ear DCS.

- Venous bubbles can partially or completely block the veins draining various organs leading to reduced organ blood flow (venous obstruction). Venous obstruction in turn leads to tissue hypoxia, cell injury and death. This is one of the secondary mechanisms of injury in Spinal Cord DCS.

- Venous bubbles carried to the lung as emboli (called venous gas emboli or VGE) can patially block the flow of blood through the lung leading to fluid build up (pulmonary edema) and decreased gas exchange. The result is systemic hypoxia and hypercarbia. This is the mechanism of damage in Pulmonary DCS.

- Arterial bubbles can act as emboli blocking the blood supply of almost any tissue leading to hypoxia, cell injury and death. Arterial gas embolism and autochotonous bubble formation are thought be the primary mechanisms of injury in Cerebral (brain) DCS.

The damage done by the direct bubble effect occurs within a relatively short period of time (a few minutes to hours). The primary treatment for these effects is recompression. Recompression will compress the bubble to a smaller diameter, restore blood flow, decrease venous congestion, and improve gas exchange in the lungs and tissues. It also increases the speed at which the bubbles outgas and collapse.

3-9.3.4 **Indirect Bubble Effects.** Bubbles may also exert their effects indirectly because a bubble 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 eliminate the foreign body. Typical reactions include:

- Blood vessels become "leaky" due to damage to the endothelial lining cells and chemical release. Blood plasma leaks out while blood cells remain inside. The blood becomes thick and more difficult to pump. Organ blood flow is reduced.

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

- The injured tissue releases fats that clump together in the bloodstream. These fat clumps act 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.

Indirect bubble effects take place over a longer period of time than the direct bubble 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 other therapies are often required.

3-9.3.5 **Symptoms of Decompression Sickness.** Decompression sickness is generally divided into two categories. Type I decompression sickness involves the skin, lymphatic system, muscles and joints and is not life threatening. Type II decompression sickness (also called serious decompression sickness) involves the nervous system, respiratory system, or circulatory system. Type II decompression sickness may become life threatening. Because the treatment of Type I and Type II decompression sickness may be different, it is important to distinguish between these two types. Symptoms of Type I and Type II decompression sickness may be present at the same time.

When the skin is involved, the symptoms are itching or burning usually accompanied by a rash. Involvement of the lymphatic system produces swelling of regional lymph nodes or an extremity. Involvement of the musculoskeletal system produces pain, which in some cases can be excruciating. 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 occur. Bubbles in the inner ear produce hearing loss and vertigo. Bubbles in the lungs can cause coughing, shortness of breath, and hypoxia, a condition referred to as "the chokes." This condition may prove fatal. A large number of bubbles in the circulation can lead to cardiovascular collapse and death. Unusual fatigue or exhaustion after a dive is probably due to bubbles in unusual locations and the biochemical changes they have induced. While not attributable to a specific organ system, unusual fatigue is a definite symptom of decompression sickness.

3-9.3.5.1 ***Time Course of Symptoms.*** Decompression sickness usually occurs after surfacing. If the dive is particularly arduous or decompression has been omitted, however, the diver may experience decompression sickness before reaching the surface.

After surfacing, there is a latency period before symptoms appear. This may be as short as several minutes to as long as several days. Long, shallow dives are generally associated with longer latencies than deep, short dives. For most dives, the onset of decompression sickness can be expected within several hours of surfacing.

3-9.3.6 **Treating Decompression Sickness.** 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 Volume 5.

3-9.3.7 **Preventing Decompression Sickness.** 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, produces 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 that permits average divers to surface safely from normal working dives without an unacceptable incidence of decompression sickness.

3-10 Thermal Problems In Diving

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 environmental conditioning when external conditions tend toward cold or hot extremes.

Thermal problems, arising from exposure to various temperatures of water, pose a major consideration when planning operational dives and selecting equipment. Bottom time may be limited more by a diver's intolerance to heat or cold than his exposure to increased oxygen partial pressures or the amount of decompression required.

The diver's thermal status will affect the rate of inert gas uptake and elimination. Recent studies suggest divers who are warm on the bottom but cold during decompression may more susceptible to decompression sickness. This may require modification of a diver's decompression schedule. Rewarming before a repetitive dive is as important as accounting for residual nitrogen levels.

3-10.1 **Regulating Body Temperature.** 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 dilate to permit more of the heated blood to reach the body surfaces, and the sweat glands increase their activity.

Maintaining proper body temperature is particularly difficult for a diver working underwater. The principal temperature control problem encountered by divers is 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.

3-10.2 **Excessive Heat Loss (Hypothermia).** Hypothermia is a lowering of the core temperature of the body. 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. 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).

3-10.2.1 **Causes of Hypothermia.** Hypothermia in diving occurs when the difference between the water and body temperature is large enough for the body to lose more heat than it produces. 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 that stirs the water in contact with the skin creates turbulence that carries off heat (convection). Heat loss is caused not 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.

3-10.2.2 **Symptoms of Hypothermia.** In mild cases, the victim will experience uncontrolled shivering, slurred speech, imbalance, and/or poor judgment. Severe cases of hypothermia are characterized by loss of shivering, impaired mental status, irregular heartbeat, and/or very shallow pulse or respirations. This is a medical emergency. The signs and symptoms of falling core temperature are given in Table 3-1, though individual responses to falling core temperature will vary. At extremely low temperatures or with prolonged immersion, body heat loss reaches a point at which death occurs.

3-10.2.3 **Treatment of Hypothermia.** To treat mild hypothermia, passive and active rewarming measures may be used and should be continued until the victim is sweating. Rewarming techniques include:

Passive:

- Remove all wet clothing.
- Wrap victim in a blanket (preferably wool).
- Place in an area protected from wind.
- If possible, place in a warm area (i.e. galley).

Active:

- Warm shower or bath.
- Place in a very warm space (i.e. engine room).

To treat severe hypothermia avoid any exercise, keep the victim lying down, initiate only passive rewarming, and immediately transport to the nearest medical treatment facility.

CAUTION **Do not institute active rewarming with severe cases of hypothermia.**

WARNING **CPR should not be initiated on a severely hypothermic diver unless it can be determined that the heart has stopped or is in ventricular fibrillation. CPR should not be initiated in a patient that is breathing.**

3-10.2.4 **Prevention of Hypothermia.** 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 1 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.

Hypothermia can be insidious and cause problems without the diver being aware of it. The diver should wear appropriate thermal protection based upon the water temperature and expected bottom time (See Chapter 6). 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. Acclimatization, adequate hydration, experience, and common sense all play a role in preventing hypothermia. Provide the diver and topside personnel adequate shelter from the elements. Adequate predive hydration is essential.

Heat loss through the respiratory tract becomes an increasingly significant factor in deeper diving. Inhaled gases are heated in the upper respiratory tract and more energy is required to heat the denser gases encountered at depth. In fact, a severe respiratory insult can develop if a diver breathes unheated gas while making a deep saturation dive in cold water. Respiratory gas heating is required in such situations.

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

Core Temperature °F	°C	Symptoms
98	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, 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

3-10.3 **Other Physiological Effects of Exposure to Cold Water.** In addition to hypothermia, other responses to exposure to cold water create potential hazards for the diver.

3-10.3.1 **Caloric Vertigo.** The eardrum does not have to rupture for caloric vertigo to occur. Caloric vertigo can occur simply as the result of having water enter the external ear canal on one side but not the other. The usual cause is a tight fitting wet suit hood that allows cold water access to one ear, but not the other. It can also occur when one external canal is obstructed by wax. Caloric vertigo may occur suddenly upon entering cold water or when passing through thermoclines. The effect is usually short lived, but while present may cause significant disoriention and nausea.

3-10.3.2 **Diving Reflex.** Sudden exposure of the face to cold water or immersion of the whole body in cold water may cause an immediate slowing of the heart rate (bradycardia) and intense constriction of the peripheral blood vessels. Sometimes abnormal heart rhythms accompany the bradycardia. This response is known as the *diving reflex*. Removing or losing a facemask in cold water can trigger the diving reflex. It is still not known whether cardiac arrhythmias associated with the diving reflex contribute to diving casualties. Until this issue is resolved, it is prudent for divers to closely monitor each other when changing rigs underwater or buddy breathing.

3-10.3.3 **Uncontrolled Hyperventilation.** If a diver with little or no thermal protection is suddenly plunged into very cold water, the effects are immediate and 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. The lack of breathing control makes survival in rough water very unlikely.

3-10.4 Excessive Heat Gain (Hyperthermia). Hyperthermia is a raising of the core temperature of the body. Hyperthermia should be considered a potential risk any time air temperature exceeds 90°F or water temperature is above 82°F. 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 body core temperature should not exceed 102.2°F (39°C). By the time the diver's core temperature approaches 102°F noticeable mental confusion may be present.

3-10.4.1 **Causes of Hyperthermia.** Divers are susceptible to hyperthermia when they are unable to dissipate their body heat. This may result from high water temperatures, protective garments, rate of work, and the duration of the dive. Predive heat exposure may lead to significant dehydration and put the diver at greater risk of hyperthermia.

3-10.4.2 **Symptoms of Hyperthermia.** 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. In severe cases of hyperthermia (severe heat exhaustion or heat stroke), the victim will experience disorientation, tremors, loss of consciousness and/or seizures.

3-10.4.3 **Treatment of Hyperthermia.** The treatment of all cases of hyperthermia shall include cooling of the victim to reduce the core temperature. In mild to moderate hyperthermia cooling should be started immediately by removing the victim's clothing, spraying him with a fine mist of lukewarm-to-cool water, and then fanning. This causes a large increase in evaporative cooling. Avoid whole body immersion in cold water or packing the body in ice as this will cause vasoconstriction which will decrease skin blood flow and may slow the loss of heat. Ice packs to the neck, armpit or groin may be used. Oral fluid replacement should begin as soon as the victim can drink and continue until he has urinated pale to clear urine several times. If the symptoms do not improve, the victim shall be transported to a medical treatment facility.

Severe hyperthermia is a medical emergency. Cooling measures shall be started and the victim shall be transported immediately to a medical treatment facility. Intravenous fluids should be administered during transport.

Table 3-2. *Signs of Heat Stress.*

Least Severe	High breathing rate
	Feeling of being hot, uncomfortable
	Low urine output
	Inability to think clearly
	Fatigue
	Light-headedness or headache
	Nausea
	Muscle cramps
	Sudden rapid increase in pulse rate
	Disorientation, confusion
	Exhaustion
	Collapse
Most Severe	Death

3-10.4.4 **Prevention of Hyperthermia.** Acclimatization, adequate hydration, experience, and common sense all play a role in preventing hyperthermia. Shelter personnel from the sun and keep the amount of clothing worn to a minimum. Adequate predive hydration is essential. Alcohol or caffeine beverages should be avoided since they can produce dehydration. Medications containing antihistamines or aspirin should not be used in warm water diving. Physically fit individuals and those with lower levels of body fat are less likely to develop hyperthermia. Guidlines for diving in warm water are contained in Chapter 6.

Acclimatization is the process where repeated exposures to heat will reduce (but not eliminate) the rise in core temperature. At least 5 consecutive days of acclimatization to warm water diving are needed to see an increased tolerance to heat. Exercise training is essential for acclimation to heat. Where possible, acclimatization should be completed before attempting long duration working dives. Acclimatization should begin with short exposures and light workloads. All support personnel should also be heat acclimatized. Fully acclimatized divers can still develop hyperthermia, however. Benefits of acclimatization begin to disappear in 3 to 5 days after stopping exposure to warm water.

3-11 SPECIAL MEDICAL PROBLEMS ASSOCIATED WITH DEEP DIVING

3-11.1 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 fsw and the severity appears to be both depth and compression rate dependent. With slow compression, depth of 1000 fsw may be achieved with relative freedom from HPNS. Beyond 1000 fsw, 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.

3-11.2 **Compression Arthralgia.** Most divers will experience pain in the joints during compression on deep dives. This condition is called *compression arthralgia*. The shoulders, knees, writs, and hips are the joints most commonly affected. The fingers, lower back, neck, and ribs may also be involved. The pain may be a constant deep ache similar to Type I decompression sickness, or a sudden, sharp, and intense but short-lived pain brought on my movement of the joint. These pains may be accompanied by “popping” or “cracking” of joints or a dry “gritty” feeling within the joint.

The incidence and intensity of compression arthralgia symptoms are dependent on the depth of the dive, the rate of compression, and individual susceptibility. While primarily a problem of deep saturation diving, mild symptoms may occur with rapid compression on air or helium-oxygen dives as shallow as 100 fsw. In deep helium saturation dives with slower compression rates, symptoms of compression arthralgia usually begins between 200 and 300 fsw, and increase in intensity as deeper depths are attained. Deeper than 600 fsw, compression pain may occur even with extremely slow rates of compression.

Compression joint pain may be severe enough to limit diver activity, travel rate, and depths attainable during downward excursion dives from saturation. Improvement is generally noted during the days spent at the saturation depth but, on occasion, these pains may last well into the decompression phase of the dive until shallower depths are reached. Compression pain can be distinguished from decompression sickness pain because it was present before decompression was started and does not increase in intensity with decreasing depth.

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

3-12 OTHER DIVING MEDICAL PROBLEMS

3-12.1 **Dehydration.** Dehydration is a concern to divers, particularly in tropical 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.

3-12.1.1 **Causes of Dehydration.** Dehydration usually results from inadequate fluid intake and/or excessive perspiration in hot climates. Unless adequate attention is paid to hydration, there is a significant chance the diver in a hot climate will enter the water in a dehydrated state.

Immersion in water creates a special situation that can lead to dehydration in its own right. The water pressure almost exactly counterbalances the hydrostatic pressure gradient that exists from head to toe in the circulatory system. As a result, blood which is normally pooled in the leg veins is translocated to the chest, causing an increase central blood volume. The body mistakenly interprets the increase in central blood as a fluid excess. A reflex is triggered leading to an increase in urination, a condition called *immersion diuresis*. The increased urine flow leads to steady loss of water from the body and a concomitant reduction in blood volume during the dive. The effects of immersion diuresis are felt when the diver leaves the water. Blood pools once again in the leg veins. Because total blood volume is reduced, central blood volume falls dramatically. The heart may have difficulty getting enough blood to pump. The diver may experience lightheadness or faint while attempting to climb out of the water on a ladder or while standing on the stage. This is the result of a drop in blood pressure as the blood volume shifts to the legs. More commonly the diver will feel fatigued, less alert, and less able to think clearly than normal. His exercise tolerance will be reduced.

3-12.1.2 **Preventing Dehydration.** Dehydration is felt to increase the risk of decompression sickness. Divers should monitor their fluid intake and urine output during diving operations to insure that they keep themselves well hydrated. During the dive itself, there is nothing one can do to block the effects of immersion diuresis. Upon surfacing they should rehydrate themselves as soon as the opportunity presents itself.

3-12.2 Immersion Pulmonary Edema. Immersion in water can cause fluid to leak out of the circulation system and accumulate first in the interstitial tissues of the lungs then in the alveoli themselves. This condition is called *immersion pulmonary edema*. The exact mechanism of injury is not know, but the condition is probably related to the increase in central blood volume that occurs during immersion (see description above). Contributing factors include immersion in cold water, negative pressure breathing, and overhydration pre-dive, all of which enhance the increase in central blood volume with immersion. Heavy exercise is also a contributor.

Symptoms may begin on the bottom, during ascent, or shortly after surfacing and consist primarily of cough and shortness of breath. The diver may cough up blood tinged mucus. Chest pain is notably absent. A chest x-ray shows the classic pattern of pulmonary edema seen in heart failure.

A diver with immersion pulmonary edema should be placed on surface oxygen and transported immediately to a medical treatment facility. Signs and symptoms will usually resolve spontaneously over 24 hours with just bed rest and 100% oxygen.

Immersion pulmonary edema is a relatively rare condition, but the incidence appears to be increasing perhaps because of an over-emphasis on the need to hydrate before a dive. Adequate pre-dive hydration is essential, but overhydration is to be avoided. Beyond avoiding overhydration and negative pressure breathing situations, there is nothing the diver can do to prevent immersion pulmonary edema.

3-12.3 **Carotid Sinus Reflex.** External pressure on the carotid artery from a tight fitting neck dam, wet suit, or dry suit can activate receptors in the arterial wall, causing a decrease in heart rate with possible loss of consciousness. Using an extra-tight-fitting dry or wet suit or tight neck dams to decrease water leaks increase the chances of activation of the carotid reflex and the potential for problems.

3-12.4 **Middle Ear Oxygen Absorption Syndrome.** Middle ear oxygen absorption syndrome refers to the negative pressure that 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 an oxygen dive. Following the dive, the tissues of the middle ear slowly absorb the oxygen. 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.

3-12.4.1 **Symptoms of Middle Ear Oxygen Absorption Syndrome.** 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.

3-12.4.2 **Treating Middle Ear Oxygen Absorption Syndrome.** Equalizing the pressure in the middle ear using a normal Valsalva maneuver or the diver's procedure of choice, such as swallowing or 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.

3-12.5 **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.

3-12.6 Blast Injury. 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 passes 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, do not readily transmit the overpressure of the shock wave. As a result, the tissues that line the air spaces are 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 500 psi or greater will cause injury to the lungs and intestinal tract.

The extent of injury is also determined in part by the degree to which the diver's body is submerged. For an underwater blast, any part of the body that is out of the water is not 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.

3-12.7 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. 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 Diving Medical Personnel.

Unless preventive measures are taken, otitis externa is very likely to occur during diving operations, causing unnecessary discomfort and restriction from diving. *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 2 percent acetic acid in aluminum acetate (e.g., Otic Domboro) 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 5 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 5-minute duration shall be timed with a watch. If the solution does not remain in the ear a full 5 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. The external ear canal can be examined periodically with an otoscope to detect the presence of ear wax. If the eardrum cannot be seen during examination, the ear canal should be flushed gently with water, dilute hydrogen peroxide, or sodium bicarbonate solutions to remove the excess cerumen. 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 divers do not adhere to prophylactic measures.

3-12.8 Hypoglycemia. Hypoglycemia is an abnormally low blood sugar (glucose) level. Episodes of hypoglycemia are common in diabetics and pre-diabetics, but may also occur in normal individuals. Simply missing a meal tends to reduce blood sugar levels. 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 symptoms even in an individual who ordinarily has no abnormality in this respect.

Symptoms of hypoglycemia include unusual hunger, excessive sweating, numbness, chills, headache, trembling, dizziness, confusion, incoordination, anxiety, and in severe cases, loss of consciousness.

If hypoglycemia is present, giving sugar by mouth relieves the symptoms promptly and proves the diagnosis. If the victim is unconscious, glucose should be given intravenously.

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, attention to proper nutrition is required. Prior to long, cold, arduous dives, divers should be encouraged to load up on carbohydrates. For more information, see Naval Medical Research Institute (NMRI) Report 89-94.

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CHAPTER 4

Dive Systems

4-1 INTRODUCTION

4-1.1 **Purpose.** The purpose of this chapter is to promulgate general policy for maintaining diving equipment and systems.

4-1.2 **Scope.** This chapter provides general guidance applicable to maintaining all diving equipment and diving systems. Detailed procedures for maintaining diving equipment and systems are found in applicable military and manufacturer's operating and maintenance (O&M) manuals and Planned Maintenance System (PMS) Maintenance Requirement Cards (MRC).

4-2 GENERAL INFORMATION

4-2.1 **Document Precedence.** If a conflict arises between the documents containing the maintenance procedures for diving equipment and systems, the following actions are required:

1. PMS/MRC takes precedence.

2. If PMS/MRC is inadequate or incorrect, the applicable military O&M manual takes precedence. Report inadequate or incorrect PMS via a PMS feedback report in accordance with current PMS instructions.

3. If PMS/MRC and applicable military O&M manual are inadequate or incorrect, the manufacturer's technical manual takes precedence. Report inadequate or incorrect military technical manual information in accordance with procedures in the affected technical manual.

Call NAVSEA or NAVFAC prior to disregarding any required maintenance procedures on certified diving equipment. Failure to do so may compromise certification.

4-2.2 **Equipment Authorized For Navy Use (ANU).** Diving equipment used to conduct diving operations shall be authorized for use by NAVSEA/00C Diving Equipment Authorized For Navy Use (ANU) list or hold a current NAVSEA or NAVFAC system safety certification certificate. Naval Sea Systems Command (Code 00C3B), Supervisor of Diving is the cognizant authority for the NAVSEA/00C ANU list. Surface supplied diving systems, hyperbaric chamber systems, and selected free swimming scuba underwater breathing apparatus shall be certified in accordance with *U.S. Navy Diving and Manned Hyperbaric System Safety Certification Manual* (SS521-AA-MAN-010).

The publication for Continuation of Certification Handbook For U.S. Navy Diving Systems, (SS521-AB-HBK-010) also provides information concerning maintaining system certification.

4-2.3 **System Certification Authority (SCA).** Naval Sea Systems Command Code 00C4 is SCA for all afloat and portable diving and hyperbaric systems. Naval Facilities Engineering Command Code 00CE is SCA for all shore-based diving and hyperbaric systems. Naval Sea Systems Command Code 07Q is SCA for submarine-employed Dry Deck Shelters and one atmosphere diving systems.

4-2.4 **Planned Maintenance System.** Diving equipment shall be maintained in accordance with the applicable PMS package. Failure to maintain equipment in accordance with current PMS guidance reduces the equipment reliability and may void the system safety certification for formally certified systems.

4-2.5 **Alteration of Diving Equipment.** Diving equipment shall not be modified or altered from approved configuration unless prior written approval has been granted by the applicable diving equipment technical program manager.

4-2.5.1 **Technical Program Managers for Shore-Based Systems.** Alterations for shore-based systems are managed by Naval Facilities Engineering Command (Code 00CE), who is the cognizant technical authority for the development and approval of alterations to shore-based systems.

4-2.5.2 **Technical Program Managers for Other Diving Apparatus.** The technical program managers for other diving apparatus are:

- MK 16 MOD 0 - NAVSEASYSCOM (PMS NSW)
- MK 16 MOD 1 - NAVSEASYSCOM (PMS-EOD)
- MK 20 - NAVSEASYSCOM (SEA 00C)
- MK 21 - NAVSEASYSCOM (SEA 00C)
- MK 25 - NAVSEASYSCOM (PMS NSW)
- Dry Deck Shelter - NAVSEASYSCOM (PMS 399)

4-2.6 **Operating and Emergency Procedures.** Operating procedures (OPs) are detailed check sheets for operating the diving system and for performing various system-related tasks. All diving and recompression chamber systems shall be operated in accordance with a set of NAVSEA or NAVFAC approved operating procedures (OPs) and Emergency Operating Procedures (EPs) and requires the Commanding Officer's or OIC's signature on the cover page as final review.

4-2.6.1 **Standardized OP/EPs.** Standardized diving equipment such as the Light Weight MK 3 Surface Supplied Diving System, Transportable Recompression Chamber System (TRCS), and class-certified equipment such as the MK 16 and MK 25 Underwater Breathing Apparatus shall be operated per a single set of standardized OP/EPs that are included as part of the system O&M Manual.

Proposed changes/updates to OP/EPs for standardized diving equipment shall be submitted as a formal change proposal to the respective O&M Manual in accordance with directions contained therein.

4-2.6.2 **Non-standardized OP/EPs.** Diving and diving support equipment such as ships, small boats, and unique shore facility surface supplied diving and recompression chamber systems shall be operated in accordance with a single set of standard OP/EPs that are developed at the command level and approved for use after validation by NAVSEA Code 00C3 or NAVFAC Code 00CE. Proposed changes/updates to OPs/EPs for non-standardized diving equipment shall be submitted to the applicable approval authority. The following addresses are provided to assist in submitting proposed OP/EP changes and updates.

Submit proposed OP/EP changes and updates for afloat, portable diving and recompression chamber systems, and class-certified equipment to:

COMNAVSEASYSCOM (Code 00C3)
Washington Navy Yard Bldg. 197
1333 Isaac Hull Ave., SE Stop 1073
Washington, DC 20376-1076

Submit proposed OP/EP changes and updates for fixed, shore-based facilities to:

NAVFACENGSERCEN EAST COAST DET (Code 07FH)
Washington Navy Yard, Bldg. 218
1435 10th Street SE, Suite 3000
Washington, DC 20374-5063

4-2.6.3 **OP/EP Approval Process.** Submission of OPs/EPs for approval (if required) must precede the requested on-site survey date by 90 calendar days to allow complete review and resolution of questions. Follow these procedures when submitting OPs/EPs for approval:

- The command shall validate in the forwarding letter that the OPs/EPs are complete and accurate.
- The command must verify that drawings are accurate. Accurate drawings are used as a guide for evaluating OPs/EPs. Fully verified system schematics/drawings with components, gas consoles, manifolds, and valves clearly labeled shall be forwarded with the OPs/EPs.
- Approved OPs/EPs shall have the revision date listed on each page and not have any changes without written NAVSEA/NAVFAC approval.
- The command shall retain system documentation pertaining to DLSS approval, i.e., PSOBs, supporting manufacturing documentation, and OPs/EPs.

4-2.6.4 **Format.** The format for OPs/EPs is as follows:

- System: (Name or description, consistent with drawings)
- Step, Component, Description, Procedure, Location, Initials, Note (read in seven columns)

4-2.6.5 **Example.**

- System: High Pressure Air
- Step/Component/Description/Procedure/Location /Initials /Note

  1. ALP-15/Reducer outlet/Open/Salvage Hold/Initials/Note
  2. ALP-GA-7/Reducer outlet/Record Pressure/Salvage Hold/Initials/Note 1

The operator executing the procedure shall initial the Check column. Hazards and items of particular concern shall be identified in the Note column.

Once NAVSEA or NAVFAC has approved the system OP/EPs, they shall not be changed without specific written approval from NAVSEA or NAVFAC.

4-3 DIVER'S BREATHING GAS PURITY STANDARDS

4-3.1 **Diver's Breathing Air.** Diver's air compressed from ANU or certified diving system sources shall meet the U.S. Military Diver's Breathing Air Standards contained in Table 4-1.

Table 4-1. *U.S. Military Diver's Compressed Air Breathing Purity Requirements for ANU Approved or Certified Sources.*

Constituent	Specification
Oxygen (percent by volume)	20-22%
Carbon dioxide (by volume)	1,000 ppm (max)
Carbon monoxide (by volume)	20 ppm (max)
Total hydrocarbons (as CH_4 by volume)	25 ppm (max)
Odor and taste	Not objectionable
Oil, mist, particulates	5 mg/m^3 (max)

Diver's breathing air may be procured from commercial sources if a source of military diver's air is not readily available. Diver's air procured from commercial sources shall be certified in writing by the vendor as meeting the purity standards of FED SPEC BB-A-1034 Grade A Source I (pressurized container) or Source II (compressor) air. Specifications for this standard are outlined in Table 4-2.

4-3.2 **Diver's Breathing Oxygen.** Oxygen used for breathing at 100-percent concentrations and for mixing of diver's breathing gases shall meet Military Specification

***Table 4-2.** Diver's Compressed Air Breathing Requirements if from Commercial Source.*

Constituent	Specification Source I Source II
Oxygen (percent by volume)	20-22%
Carbon dioxide (by volume)	500 ppm (max)
Carbon monoxide (by volume)	10 ppm (max)
Total hydrocarbons [as Methane (CH_4) by volume]	25 ppm (max)
Odor	Not objectionable
Oil, mist, particulates	.005 mg/l (max)
Separated Water	None
Total Water	0.02 mg/l (max)
Halogenated Compounds (by volume):	
Solvents	0.2 ppm (max)
Reference: FED SPEC BB-A-1034 B	

MIL-PRF-27210G, Oxygen, Aviators Breathing, Liquid and Gaseous. The purity standards are contained in Table 4-3.

4-3.3 **Diver's Breathing Helium.** Helium used for diver's breathing gas shall meet Military Specification, A-A-59503 Propellant Pressurizing Agent Helium, Type I Gaseous Grade B, Respirable Helium. The purity standards are contained in Table 4-4.

4-3.4 **Diver's Breathing Nitrogen.** Nitrogen used for divers breathing gas shall meet Federal Specification A-A-59503 Nitrogen, Technical. The purity standards are contained in Table 4-5.

4-4 DIVER'S AIR SAMPLING PROGRAM

NAVSEA Code 00C manages the diver's breathing air sampling program in accordance with OPNAVINST 3150.27 (series). The purpose of the air sampling program is to:

- Provide technical support for the operation and maintenance of diver's breathing air compressors and diving air storage systems.
- Provide general guidance concerning use of local commercial air sampling sources, including the evaluation of commercial air sampling capabilities and equipment.
- Perform program management for centrally funded air sampling services as directed by CNO Code N773.

Table 4-3. Diver's Compressed Oxygen Breathing Purity Requirements.

Constituent	Specification
General Note: Gaseous and liquid oxygen shall contain not less than 99.5% by volume. The remainder, except for moisture and minor constituents specified below, shall be Argon and Nitrogen.	
Type I Gaseous	
Oxygen (percent by volume)	99.5%
Carbon dioxide (by volume)	10 ppm (max)
Methane (CH_4 by volume)	50 ppm (max)
Acetylene (C_2H_2)	0.1 ppm (max)
Ethylene (C_2H_4)	0.4 ppm (max)
Ethane (C_2H_6 and other hydrocarbons)	6.0 ppm (max)
Nitrous Oxide (N_2O by volume)	4.0 ppm (max)
Halogenated Compounds (by volume):	
Refrigerants	2.0 ppm (max)
Solvents	0.2 ppm (max)
Moisture (water vapor measured by ppm or measured by dew point)	7 ppm (max) <-82°F
Odor	Odor free
Type II Liquid	
Oxygen (percent by volume)	99.5%
Carbon dioxide (by volume)	5 ppm (max)
Methane (CH_4 by volume)	25 ppm (max)
Acetylene (C_2H_2)	0.05 ppm (max)
Ethylene (C_2H_4)	0.2 ppm (max)
Ethane (C_2H_6 and other hydrocarbons)	3.0 ppm (max)
Nitrous Oxide (N_2O by volume)	2.0 ppm (max)
Halogenated Compounds (by volume):	
Refrigerants	1.0 ppm (max)
Solvents	0.10 ppm (max)
Moisture (water vapor measured by ppm or measured by dew point)	7 ppm (max) <-82°F
Odor	Odor free
Reference: Military Specification MIL-PRF-27210G	

- Collaborate with other government agencies and commercial industry on gas purity standards and sampling procedures related to diver's breathing gases.

4-4.1 **Maintenance Requirements.** Taking periodic air samples is a required maintenance action and shall be performed in accordance with the PMS card(s) applicable to the compressor or system producing diver's breathing air. Each diver

Table 4-4. *Diver's Compressed Helium Breathing Purity Requirements.*

Constituent	Specification
Helium (percent by volume)	99.997%
Moisture (water vapor)	9 ppm (max)
Dew Point (not greater than)	-78°F
Hydrocarbons (as Methane)	1 ppm (max)
Oxygen	3 ppm (max)
Nitrogen + Argon	5 ppm (max)
Neon	23 ppm (max)
Hydrogen	1 ppm (max)
Reference: Military Specification MIL-PRF-27407B	

breathing-air source in service must be sampled approximately every 6 months (within the interval between 4 and 8 months following the last accomplishment), when contamination is suspected and after system overhaul.

Do not use a compressor that is suspected of producing contaminated air or that has failed an air sample analysis until the cause of the problem has been corrected and a satisfactory air sample analysis has been obtained validating the production of acceptable air.

Diving systems that do not have a high-pressure (HP) air compressor within the scope of certification shall only be charged with air produced by HP air compressors listed on the ANU list and must have all applicable PMS completed up to date, including air sample requirements. Examples of these types of systems include MK 3 LWDS, Roper Cart, and various diving boats. HP banks on these systems need not be sampled unless contamination is suspected.

Air drawn from submarine HP air storage banks for use as diver's breathing air shall be sampled in accordance with the PMS maintenance requirement card applicable to the system, i.e., dry deck shelter system, submarine escape trunk, scuba charging station. See paragraph 4-4.2 for additional information on system line-up for sampling compressors where a sampling connection cannot be made immediately downstream from the last air filtration device.

Table 4-1 shows the minimum purity requirements for diving air produced by ANU-approved and certified diving air compressors. Air sampling services may be procured locally from government or commercial air analysis facilities, or may be acquired by utilizing analysis services coordinated via Naval Surface Warfare Center, Panama City, Florida (NSWC-PC).

NOTE **The most recent air sample analysis report shall be maintained on file for each air compressor (by compressor serial number) used to produce diver's breathing air.**

4-4.2 General Air Sampling Procedures. The following general information is provided to assist commands in managing air sample analysis programs.

Ensure all applicable PMS has been completed on the compressor and associated filtration system prior to taking an air sample.

Table 4-5. *Diver's Compressed Nitrogen Breathing Purity Requirements.*

Class I Oil Free, Type I Gaseous & Type II Liquid		
	Specification/Grade	
Constituent	**A**	**B**
Nitrogen	99.95%	99.95%
Oxygen	0.05%	0.50%
Moisture (water vapor)	.02 mg/l	.02 mg/l
Total Hydrocarbons (as methane by volume)	50 ppm	50 ppm
Odor	None	None

Note: Type I Nitrogen shall not contain any solid particles whose dimensions are greater than 50 microns. A 10 micron or better nominal filter at or close to the cylinder charging manifold will be used.

Reference: Federal Specification A-A-59155

- When sampling from HP 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 down stream of the last compressor-mounted air treatment device (moisture separator, filter, etc.). Some systems do not have fittings that allow samples to be taken from the system at a location other than the 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 charging connection.

- When sampling from a low-pressure (LP) breathing-air system, separate air samples shall be taken from each LP compressor connected to the system. Samples shall be taken from each LP compressor as close to the compressor as possible, but downstream of the last compressor installed air treatment device (moisture separator, filter, etc.). Some systems do not have fittings that allow samples to be taken at connections other than the diver’s manifold. In this case, a HP source 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.

NOTE Failure to purge the system line-up of air produced from other compressors or storage flasks will lead to an invalid air sample for the compressor being sampled.

- Ensure that the compressor being sampled has reached full operating status (proper operating temperature, oil pressure, and air pressure) and is properly lined up to deliver air to the sample kit.

- Ensure that the compressor's intake is clear of any potential sources of contamination (including consideration of ambient smog levels in areas where smog is a problem).

- Follow the procedures on applicable air sample MRC card.

- Follow the instructions for operation of the air sampling kit.

4-4.3 **NSWC- PC Air Sampling Services.** The following applies to centrally funded air sampling services coordinated by NSWC-PC. Due to limited funding, commands are requested to schedule all compressors and associated samples to be taken at the same time. NSWC-PC coordinates air sampling services with a commercial contractor. Commands are not authorized to communicate directly with the commercial contractor. Sampling services are provided at no cost to the command. To request air sampling services, fill out and fax Air Sampling services request to NSWC-PC (Attn: Air Sampling). Telephone numbers are listed in Appendix 1C.

- The user must provide the sample expiration date, the number and type (HP or LP) of samples required, a complete mailing address, user point of contact and phone number. Air sample kits will not be shipped until the required information is received.

- Allow a minimum of 5 working days after submitting a properly filled out request form for delivery of a sampling kit in CONUS. Kits will be sent via commercial air with a prepaid return mailer. Incomplete sample requests cannot be acted on and will result in delay of shipping of sample kit.

- Allow a minimum of 3 weeks after submitting a properly filled out request form for delivery of a sampling kit if overseas. Kits will be sent via certified priority mail for overseas/FPO-APO addressees with prepaid return mailing. Incomplete sample requests cannot be acted on and will result in delay of shipping of sample kit.

- Detailed instructions are included with each sample kit. It is imperative to follow those instructions and the instructions on the applicable compressor air sampling MRC card.

- Air samples shall be taken and returned to NSWC-PC within 5 working days of receipt of the air sample kit to preclude incurring late fees.

- Air sample analysis reports for samples that meet air purity standards will be mailed to the command. Commands will be notified by quickest means possible of any samples that do not meet minimum purity requirements.

- The user will be contacted immediately by phone and/or message by NSWC-PC if the sample fails to meet established purity standards. The user will discontinue use of the air source until cause of contamination is corrected. Corrective action must be taken prior to laboratory retest.

4-4.4 **Local Air Sampling Services.** Commands may use local government (e.g., shipyards, ship repair facilities, government research laboratories) or commercial laboratories to analyze diver's air samples. Commands are required to bear the cost of locally procured air sample services. Local sampling facilities must be able to analyze to U.S. Navy air purity standards.

4-5 DIVING COMPRESSORS

4-5.1 **Equipment Requirements.** Compressors used to supply diving air or transfer oxygen or mixed gases shall be listed in the NAVSEA/00C Authorized for Navy use (ANU) list or be an element of a certified diving system.

4-5.2 **Air Filtration System.** Military diving compressors shall be equipped with an air filtration system that is listed in the NAVSEA/00C Authorized for Navy use (ANU) list or be an element of a certified diving system. The term air filtration system as used here is inclusive, referring collectively to compressed gas system filters, moisture separators, air purification, air cooling, and dehydration equipment.

4-5.3 **Lubrication.** Compressors used to produce military diver's breathing air are normally of oil-lubricated, two-to-five-stage reciprocating type. Oil lubrication:

- Prevents wear between friction surfaces
- Seals close clearances
- Protects against corrosion
- Transfers heat away from heat-producing surfaces
- Transfers minute particles generated from normal system wear to the oil sump or oil filter if so equipped

A malfunctioning oil-lubricated compressor poses a contamination risk to the diver's air supply. Contamination may occur due to excess oil mist being passed out of the compressor due to excess clearances, broken parts, or overfilling the oil sump.

Gaseous hydrocarbons and carbon monoxide may also be produced should a compressor overheat to the point of causing combustion of the lubricating oil and/or gaskets and other soft goods found in the compressor. Compressor overheating may be caused by a number of events including, but not limited to: loss of cooling water or air flow, low lube oil level, malfunction of stage unloader or relief valves, friction from broken or excessively worn parts, and/or compressor operation at an RPM above its rated capacity.

Diver’s air filtration systems are designed to work with compressors operating under normal conditions, and cannot be relied on to filter or purify air from a malfunctioning compressor.

WARNING **Do not use a malfunctioning compressor to pump diver’s breathing air or charge diver's air storage flasks as this may result in contamination of the diver's air supply.**

Lubricants used in diver’s air compressors shall conform to MIL-L-17331 (2190 TEP) for normal operations, or MIL-H-17672 (2135TH) for cold weather operations. Where the compressor manufacturer specifically recommends the use of a synthetic base oil in their compressor for production of breathing air, that manufacturer recommended synthetic base oil may be used in lieu of MIL-L-17331 or MIL-H-17672 oil. Oil shall be changed out on compressors in strict accordance with the PMS requirements applicable to that compressor.

4-6 DIVING GAUGES

4-6.1 Selecting Diving System Guages. Select a gauge whose full scale reading approximates 130 percent to 160 percent of the maximum operating pressure of the system. Following this guideline, a gauge with a full scale reading of 4,000 or 5,000 psi would be satisfactory for installation in a system with a maximum operating pressure of 3,000 psi.

Selecting gauge accuracy and precision should be based on the type of system and how the gauge will be used. For example, a high level of precision is not required 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 (¼ 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 selecting the proper decompression or treatment table.

Many gauges are provided with a case blowout plug on the rear surface. The blowout plug protects 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. If a gauge fails during an operation, the isolation valve closes to prevent loss of system pressure.

4-6.2 Calibrating and Maintaining 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. Programs such as the Shipboard Gauge Calibration Program as outlined in the NAVSEA Instruction 4734.1 (series) provide authority for a command to calibrate its own gauges. Calibrated gauges not in use should be kept in a clean, dry, vibration-free environment. The Meteorology 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 that 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. Enclosures of transparent acrylic plastic, such as lucite, can be used to protect the gauges from water and salt spray. However, the enclosure must have vent passages to allow the atmospheric pressure to act on the gauge sensing element.

4-6.3 **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 ¼ 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).

4-7 COMPRESSED GAS HANDLING AND STORAGE

Handling and storing compressed gas are inherent parts of virtually all diving activities, whether conducted with scuba or surface supplied diving equipment. It is imperative that divers be familiar with the safety aspects of handling compressed gas. Diver's compressed gas shall be stored in military standard (MIL-STD) or DOT approved cylinders or ASME flasks applicable to the type and pressure levels of the compressed gas being stored.

Compressed gas shall be transported in cylinders meeting Department of Transportation (DOT) regulations applicable to the compressed gas being handled. DOT approved cylinders bear a serial number, DOT inspection stamp, a pressure rating, the date of last hydrostatic test, are equipped with applicable cylinder valve, and are appropriately color coded.

Refer to the following references for more detailed information on compressed gas handling and storage:

- *Industrial Gases, Generating, Handling and Storage*, NAVSEA Technical Manual S9086-SX-STM-000/CH-550
- *American and Canadian Standard Compressed-Gas Cylinder Valve Outlet and Inlet Connections* (ANSI-B57.1 and CSA-B96).
- *American National Standard Method of Marking Portable Compressed-Gas Containers to Identify the Material Contained* (Z48.1)
- *Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Cylinders* (CGA Pamphlet C-7).

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CHAPTER 5

Dive Program Administration

5-1 INTRODUCTION

5-1.1 Purpose. The purpose of this chapter is to promulgate general policy for maintaining and retaining command smooth diving logs, personal diving logs, personal diving records, diving mishap reports, and failure analysis reports.

5-1.2 Scope. The record keeping and reporting instructions outlined in this chapter pertain to command smooth diving logs, individual diving logs, personal diving records, diving mishap reports, and failure analysis reports.

5-2 OBJECTIVES OF THE RECORD KEEPING AND REPORTING SYSTEM

There are five 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. Information about current diving operations conducted in the Navy, the incidence of Hyperbaric Treatments, and diving mishaps is provided to the Naval Safety Center through the Diving Reporting System and by message as required in OPNAVINST 5102.1(series) via the Web Enabled Safety System (WESS). This information enables the Safety Center to identify safety-related problems associated with operating procedures and training.

3. Provide data for a personal record. OPNAVINST 3150.27 (series) requires each diver to maintain a personal diving log/history.

4. Report information about diving mishaps and casualties in accordance with the requirements of OPNAVINST 5102.1 (series) via WESS. Complete and accurate information enables the command to take appropriate action and prevent reoccurrence.

5. Report information about equipment deficiencies to the responsible technical agencies through the Failure Analysis Report (FAR) system.

5-3 RECORD KEEPING AND REPORTING DOCUMENTS

The documents established to meet the objectives of the record keeping and reporting system are:

- Command Smooth Diving Log (Figure 5-1)
- Dive Reporting System (DRS)
- Diver's Personal Dive Record (diskette or hard copy)
- Diving Mishap/Hyperbaric Treatment/Death Report, Symbol OPNAV 5102/5 (via WESS)
- Diving Mishaps reported in accordance with OPNAVINST 5102.1 (series) via WESS
- Equipment Accident/Incident Information Sheet (Figure 5-2)
- Diving Life Support Equipment Failure Analysis Report (FAR) for MK 20 AGA, MK 21 surface-supplied diving system, and open-circuit scuba (NAVSEA Form 10560/4) (Figure 5-3). FARS may be reported via the on-line reporting system at www.supsalv.org.
- Failure Analysis Report for MK 16 UBA (NAVSEA Form 10560/1) (Figure 5-4) or Failure Analysis or Inadequacy Report for MK 25. FARS maybe reported via the on-line reporting system at www.supsalv.org.

5-4 COMMAND SMOOTH DIVING LOG

The Command Smooth Diving Log is a chronological record of all dives conducted at that facility or command. It contains information on dives by personnel attached to the reporting command and dives by personnel temporarily attached to the command, such as personnel on TAD/TDY.

Dives conducted while temporarily assigned to another diving command shall be recorded in the host command's Smooth Diving Log. Additionally, record the dive in the Dive Reporting System (DRS) of the host command.

The OPNAVINST 3150.27 (series) requires commands to retain the official diving log for 3 years. The minimum data items in the Command Smooth Diving Log include:

- Date of dive
- Purpose of the dive
- Identification of divers and standby divers
- Times left and reached surface, bottom time
- Depth
- Decompression time
- Air and water temperature
- Signatures of Diving Supervisor or Diving Officer

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 1, (NAVSEA).

Figure 5-1. 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 (Diving Officer/Master Diver)								

Figure 5-1. U.S. Navy Diving Log (sheet 2 of 2).

EQUIPMENT ACCIDENT/INCIDENT INFORMATION SHEET

GENERAL

Unit point of contact ________________________________ Position ______________________

Command UIC _________________Date______________ Time of occurrence ______________

____

EQUIPMENT (indicate type of all equipment worn/used) Contributing factor______________________

UBA: SCUBA ______________ MK21 ____________________ MK20 ____________

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 5-2. Equipment Accident/Incident Information Sheet. (Sheet 1 of 2).

EQUIPMENT ACCIDENT/INCIDENT INFORMATION SHEET

Pertaining to UBA involved, fill in blanks with data required by items 1 through 9.

MK 21 ↓	MK 20 MOD 0 ↓	SCUBA ↓	MK 16 ↓	MK 25 ↓	OTHER ↓
1. Number of turns to secure topside gas umbilical supply:					
		N/A	N/A	N/A	
2. Number of turns to secure valve on emergency gas supply (EGS):					
		Reserve Up/Down	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 ________	
4. Number of turns to secure gas bottle:					
N/A	N/A	Air Bottle ________	O_2 ________ Diluent ________	O_2 Bottle ________	
5. Bottle Pressure:					
EGS _____ psig	EGS _____ psig	_____ psig	O_2 _____ psig Diluent _____ psig	_____ psig	
6. Gas Mixture:					
Primary % ______ EGS % ______		N/A	Diluent N_2O_2 _____ HeO_2 _____	N/A	
7. Data/color of electronic display:					
N/A	N/A	N/A	Primary ________ Secondary __________ __________ _______	N/A	
8. Battery voltage level:					
N/A	N/A	N/A	Primary ________ Secondary ________	N/A	
9. Condition of canister:					
N/A	N/A	N/A			

Note: If UBA involved is not listed above, provide information on separate sheet.

Figure 5-2. Equipment Accident/Incident Information Sheet. (Sheet 2 of 2).

5-5 RECOMPRESSION CHAMBER LOG

The Recompression Chamber 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 Recompression Chamber Log. the shall 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 Recompression Chamber Log must be retained for 3 years after the date of the dive. The minimum data items in the Recompression Chamber Log include:

- Date of dive
- Purpose of the dive
- Identification of diver(s)/patients(s)
- Identification of tender(s)
- Time left surface
- Time reached treatment depth
- Time reached stop
- Time left stop
- Depth/time of relief
- Change in symptoms
- Recompression chamber air temperature (if available)
- Oxygen and Carbon Dioxide % (if available)
- Medicine given
- Fluid administered
- Fluid void
- Signatures of Diving Officer, Master Diver, or Diving Supervisor

NAVAL SEA SYSTEMS COMMAND
DIVING LIFE SUPPORT EQUIPMENT FAILURE ANALYSIS REPORT (FAR)

1. Reporting Activity Name	2. Unit Identification Code ______ FAR Serial No. ______	3. Date Problem Detected (Mo/Day/Yr) ______

4. Reporting Activity Name 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 ( )
- ☐ 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 (1086) (Front) **S/N 0116-LF-105-6020**

Figure 5-3. Failure Analysis Report (NAVSEA Form 10560/4).

FAILURE ANALYSIS REPORT

(*See SS600-AH-MMA-010 for Information Concerning Use of This Form*)

Disposition: Maintain the Original of This Form in Auditable Fashion With the UBA for the Entire Period Between NAVSEA Certification Surveys. Forward Copies 1-3 (Self Mailers) to the Addresses as Shown on the Bottom Right-Hand Corner and Back of the Forms.

1. Name of Reporting Activity	Unit Identification Code	2. Report Category (*Check Applicable Block*) ☐ Safety ☐ Routine	3. Report Serial Number 4. Date Discovered
5. Deficiency Category (*Check One*) ☐ Equipment ☐ Publication	6. UBA Serial Number	7. Point of Contact for Activity	Autovon No. / Commercial No. ( )

8. Reason for Report (*Check Applicable Block*)

☐ Failure/Failure Suspected or Malfunction ☐ Damage Due to Improper Maintenance/Operation/Test ☐ Damage or Defective on Receipt ☐ Other (*Explain in Item 15*)

9. When Discovered (*Check Applicable Block*)

☐ Predive ☐ Postdive ☐ PMS ☐ During Operations ☐ Other (*Explain Here or in Item 15*)

10. System, Subsystem, or Component(s) Affected	11. Reentry Control Form No. (*Attach Copy*)

12. Description of Failure/Trouble/Discrepancy

13. Cause of Failure/Trouble/Discrepancy, If Known

14. Corrective Action Taken

15. Comments or Recommendations for Prevention or Elimination of Problems

16. Signature of Preparer	Rank/ Rate	Date Signed	17. Signature, Approving Official	Rank/ Rate	Date Approved

NAVSEA 10560/1 (12-84)

Figure 5-4. Failure Analysis Report. (NAVSEA Form 10560/1).

5-6 DIVER'S PERSONAL DIVE LOG

Although specific Navy Divers Personal Logbooks are no longer required, each Navy trained diver is still required to maintain a record of his dives in accordance with the OPNAVINST 3150.27 (series). The best way for each diver to accomplish this is to keep a copy of each Diving Log Form in a binder or folder. The Diving Log Form is generated by the Diver Reporting System (DRS) software. The record may also be kept on a personal floppy disk. These forms, when signed by the Diving Supervisor and Diving Officer, are an acceptable record of dives that 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. If an individual desires a hard copy of the dives, the diver's command can generate a report using the DRS or by submitting a written request to the Naval Safety Center.

5-7 DIVING MISHAP/CASUALTY REPORTING

Specific instructions for diving mishap, casualty, and hyperbaric treatment are provided in OPNAVINST 5102.1 (series). The Judge Advocate General (JAG) 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 this chapter.

5-8 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 (DLSE). The FAR was developed to provide a rapid response to DLSE 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 DLSE not already addressed by other FARs or reporting systems. For example, the MK 21 MOD 1, MK 20 MOD 0 mask, and all open-circuit scuba are reportable on this FAR form; the UBAs MK 16 and MK 25 are reportable on a FAR or a Failure Analysis or Inadequacy Report (FAIR) in accordance with their respective technical manuals. When an equipment failure or deficiency is discovered, the Diving Supervisor or other responsible person shall ensure that the FAR is properly prepared and distributed. Refer to paragraph 5-10 for additional reporting requirements for an equipment failure suspected as the cause of a diving accident.

An electronic version of the FAR form is also available on-line at http://www.supsalv.org. Click on Diving or 00C3 Diving. When the next screen appears, click on Failure Analysis Reporting. Follow the instructions and submit the form.

5-9 U.S. NAVY DIVE REPORTING SYSTEM (DRS)

The Dive Reporting System (DRS) is a computer-based method of recording and reporting dives required by the OPNAVINST 3150.27 (series), and replaces reporting on DD Form 2544. The computer software provides all diving commands with a computerized record of dives.

The DRS makes it easy for commands to submit diving data to the Naval Safety Center. The computer software allows users to enter dive data, transfer data to the Naval Safety Center, and to generate individual diver and command reports. The DRS was designed for all branches of the U.S. Armed Services and can be obtained through:

Commander, Naval Safety Center
Attention: Code 37
375 A Street
Norfolk, VA 23511-4399

5-10 ACCIDENT/INCIDENT EQUIPMENT INVESTIGATION REQUIREMENTS

An *accident* is an unexpected event that culminates in loss of or serious damage to equipment or injury to personnel. An *incident* is an unexpected event that 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 that do occur, however, must receive a thorough review to identify the cause and determine corrective measures to prevent further diving mishaps.

This section expands on the OPNAVINST 5102.1 (series) that requires expeditious reporting and investigation of diving related mishaps. The accident/incident equipment status reporting procedures in this chapter apply, in general, to all diving mishaps when malfunction or inadequate equipment performance, or unsound equipment operating and maintenance procedures are a factor.

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 that 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.

Contact NAVSEA/00C3 to assist diving units with investigations and data collection following a diving mishap. 00C3 will assign a representative to inspect the initial condition of equipment and to pick up or ship all pertinent records and equipment to NEDU for full unmanned testing. Upon receiving the defective equipment, NEDU will conduct unmanned tests as rapidly as possible and will then return the equipment to the appropriate activity.

NOTE **Do not tamper with equipment without first contacting NAVSEA/00C3 for guidance.**

5-11 REPORTING CRITERIA

The diving and diving related accident/incident equipment status requirements set forth in this chapter are mandatory for all U.S. Navy diving units in each of the following circumstances:

- In all cases when an accident/incident results in a fatality or serious injury.
- When an accident/incident occurs and a malfunction or inadequate performance of the equipment may have contributed to the accident/incident.

5-12 ACTIONS REQUIRED

U.S. Navy diving units shall perform the following procedure when a diving accident/incident or related mishap meets the criteria stated in paragraph 5-11.

1. Immediately secure and safeguard from tampering all diver-worn and ancillary/support equipment that may have contributed to the mishap. This equipment should also include, but is not limited to, the compressor, regulator, depth gauge, submersible pressure gauge, diver dress, buoyancy compensator/ life preserver, weight belt, and gas supply (scuba, emergency gas supply, etc.).

2. Expeditiously report circumstances of the accident/incident via WESS. Commands without WESS access should report by message (see OPNAVINST 5102.1 (series) for format requirements) to:

   - NAVSAFECEN NORFOLK VA//JJJ// with information copies to
CNO WASHINGTON DC//N773//
COMNAVSEASYSCOM WASHINGTON DC//00C// and
NAVXDIVINGU PANAMA CITY FL//JJJ//.
   - If the accident/incident is MK 16 MOD 1 related, also send information copies to PEO LMW WASHINGTON DC//PMS-EOD// and NAVEODTECHDIV INDIAN HEAD MD//70//.
   - If the accident/incident is MK 16 MOD 0 related, also send information copies to PEO LMW WASHINGTON DC//PMS-NSW//.
   - If the accident/incident occurs at a shore based facility (NAVFAC), also send information copies to NFESC EAST COAST DET WASHINGTON DC//00CE//.

3. Expeditiously prepare a **separate, written report** of the accident/incident. The report shall include:

- A completed Equipment Accident/Incident Information Sheet (Figure 5-2)
- A sequential narrative of the mishap including relevant details that might not be apparent in the data sheets

4. 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

5. Package a certified copy of all pertinent 3M records and deliver to NAVSEA/00C3 on-scene representative.

NOTE Call NAVSEA/NEDU/NAVFAC with details of the mishap or incident whenever possible. Personal contact may prevent loss of evidence vital to the evaluation of the equipment.

5-12.1 Technical Manual Deficiency/Evaluation Report. 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.

5-12.2 Shipment of Equipment. To expedite delivery, scuba, MK 16 and EGS bottles shall be shipped separately in accordance with current DOT directives and command procedures for shipment of compressed gas cylinders. Cylinders shall be forwarded in their exact condition of recovery (e.g., empty, partially filled, fully charged). If the equipment that is believed to be contributory to the accident/incident is too large to ship economically, contact NEDU to determine alternate procedures.

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APPENDIX 1A
Safe Diving Distances from Transmitting Sonar

1A-1 INTRODUCTION

The purpose of this appendix is to provide guidance regarding safe diving distances and exposure times for divers operating in the vicinity of ships transmitting with sonar. Table 1A-1 provides guidance for selecting Permissible Exposure Limits Tables; Table 1A-2 provides additional guidance for helmeted divers. Tables 1A-3 through 1A-5 provide specific procedures for diving operations involving AN/SQS-23, -26, -53, -56; AN/BSY-1, -2; and AN/BQQ-5 sonars. Table 1A-6 provides procedures for diving operations involving AN/SQQ-14, -30, and -32. Section 1A-5 provides guidance and precautions concerning diver exposure to low-frequency sonar (160-320Hz). Contact NAVSEA Supervisor of Diving (00C3B) for guidance on other sonars. This appendix has been substantially revised from Safe Diving Distances from Transmitting Sonar (NAVSEAINST 3150.2 Series) and should be read in its entirety.

1A-2 BACKGROUND

Chapter 18 of OPNAVINST 5100.23 Series is the basic instruction governing hearing conservation and noise abatement, but it does not address exposure to waterborne sound. Tables 1A-3 through 1A-6 are derived from experimental and theoretical research conducted at the Naval Submarine Medical Research Laboratory (NSMRL) and Naval Experimental Diving Unit (NEDU). This instruction provides field guidance for determining safe diving distances from transmitting sonar. This instruction supplements OPNAVINST 5100.23 Series, and should be implemented in conjunction with OPNAVINST 5100.23 Series by commands that employ divers.

The Sound Pressure Level (SPL), not distance, is the determining factor for establishing a Permissible Exposure Limit (PEL). The exposure SPLs in Tables 1A-3 through 1A-6 are based upon the sonar equation and assume omni-directional sonar and inverse square law spreading. Any established means may be used to estimate the SPL at a dive site, and that SPL may be used to determine a PEL. When the exposure level is overestimated, little damage, except to working schedules, will result. Any complaints of excessive loudness or ear pain for divers require that corrective action be taken. Section 1A-5 provides guidance for diver exposure to low-frequency active sonar (LFA), which should be consulted if exposure to LFA is either suspected or anticipated.

This appendix does not preclude the operation of any sonar in conjunction with diving operations, especially under operationally compelling conditions. It is based upon occupational safety and health considerations that should be implemented for routine diving operations. It should be applied judiciously under special operational circumstances. The guidance in Tables 1A-3 through 1A-6 is intended to facilitate the successful integration of operations.

1A-3 ACTION

Commanding Officers or Senior Officers Present Afloat are to ensure that diving and sonar operations are integrated using the guidance given by this appendix. Appropriate procedures are to be established within each command to effect coordination among units, implement safety considerations, and provide efficient operations using the guidance in Tables 1A-3 though 1A-6.

1A-4 SONAR DIVING DISTANCES WORKSHEETS WITH DIRECTIONS FOR USE

1A-4.1 **General Information/Introduction.** Permissible Exposure Limits (PEL) in minutes for exposure of divers to sonar transmissions are given in Tables 1A-3 through 1A-6.

1A-4.1.1 **Effects of Exposure.** Tables 1A-3 through 1A-5 are divided by horizontal double lines. Exposure conditions above the double lines should be avoided for routine operations. As Sound Pressure Level (SPL) increases above 215 dB for hooded divers, slight visual-field shifts (probably due to direct stimulation of the semicircular canals), fogging of the face plate, spraying of any water within the mask, and other effects may occur. In the presence of long sonar pulses (one second or longer), depth gauges may become erratic and regulators may tend to free-flow. Divers at Naval Submarine Medical Research Laboratory experiencing these phenomena during controlled research report that while these effects are unpleasant, they are tolerable. Similar data are not available for un-hooded divers but visual-field shifts may occur for these divers at lower levels. If divers need to be exposed to such conditions, they must be carefully briefed and, if feasible, given short training exposures under carefully controlled conditions. Because the probability of physiological damage increases markedly as sound pressures increase beyond 200 dB at any frequency, exposure of divers above 200 dB is prohibited unless full wet suits and hoods are worn. Fully protected divers (full wet suits and hoods) must not be exposed to SPLs in excess of 215 dB at any frequency for any reason.

1A-4.1.2 **Suit and Hood Characteristics.** There is some variation in nomenclature and characteristics of suits and hoods used by divers. The subjects who participated in the Naval Submarine Medical Research Laboratory experiments used 3/8-inch nylon-lined neoprene wet suits and hoods. Subsequent research has shown that 3/16-inch wet suit hoods provide about the same attenuation as 3/8-inch hoods. Hoods should be well fitted and cover the skull completely including cheek and chin areas. The use of wet-suit hoods as underwater ear protection is strongly recommended.

1A-4.1.3 **In-Water Hearing vs. In-Gas Hearing.** A distinction is made between in-water hearing and in-gas hearing. In-water hearing occurs when the skull is directly in contact with the water, as when the head is bare or covered with a wet-suit hood. In-gas hearing occurs when the skull is surrounded by gas as in the MK 21 diving helmet. In-water hearing occurs by bone conduction—sound incident anywhere on the skull is transmitted to the inner ear, bypassing the external and middle ear. In-gas hearing occurs in the normal way—sound enters the external ear canal and stimulates the inner ear through the middle ear.

1A-4.2 Directions for Completing the Sonar Diving Distances Worksheet. Follow the steps listed below to determine Permissible Exposure Limits (PELs) for the case when the actual dB Sound Pressure Level (SPL) at the dive site is unknown. Figure 1A-1 is a worksheet for computing the safe diving distance/exposure time. Figures 1A-2 through 1A-5 are completed worksheets using example problems. Work through these example problems before applying the worksheet to your particular situation.

Step 1. Diver Dress. Identify the type of diving equipment—wet-suit un-hooded; wet-suit hooded; helmeted. Check the appropriate entry on step 1 of the worksheet.

Step 2. Sonar Type(s). Identify from the ship's Commanding Officer or representative the type(s) of sonar that will be transmitting during the period of time the diver is planned to be in the water. Enter the sonar type(s) in step 2 of the worksheet.

Step 3. PEL Table Selection. Use the Table 1A-1 to determine which PEL table you will use for your calculations. For swimsuit diving use wet suit un-hooded tables. Check the table used in step 3 of the worksheet.

Table 1A-1. *PEL Selection Table.*

	SONAR		
DIVER DRESS:	**All except AN/SQQ -14, - 30, -32**	**AN/SQQ -14, -30, -32**	**Unknown Sonar**
Wet suit - Un-hooded	Table 1A-3	Table 1A-6	Start at 1000 yards and move in to diver comfort
Wet suit - Hooded	Table 1A-4	Table 1A-6	Start at 600 yards and move in to diver comfort
Helmeted	Table 1A-5	No restriction	Start at 3000 yards and move in to diver comfort

For guidance for sonars not addressed by this instruction, contact NAVSEA (00C32) DSN 327-2766.

NOTE If the type of sonar is unknown, start diving at 600–3,000 yards, depending on diving equipment (use greater distance if helmeted), and move in to limits of diver comfort.

Step 4. Distance to Sonar. Determine the distance (yards) to the transmitting sonar from place of diver's work. Enter the range in yards in step 4 of the worksheet.

SONAR SAFE DIVING DISTANCE/EXPOSURE TIME WORKSHEET

1. Diver dress: Wet Suit - Un-hooded ______
   Wet Suit - Hooded _____
   Helmeted _____

2. Type(s) of sonar: ____________________

3. PEL Table 1A-3 ___; 1A-4 _____; 1A-5 ___ ; 1A-6 ___

4. Range(s) to sonar (yards): _____________________

5. Estimated SPL at range(s) in step 3 (from table/column in step 3): __________________

   Reminder: If range is between two values in the table, use the shorter range.
   If the SPL is measured at the dive site, use the measured value.

6. Depth Reduction ______ dB

   Reminder: **0 if <u>not</u> helmeted, see table in instructions if helmeted**.

7. Corrected SPL (Step 5 minus Step 6) ___________________________________

8. Estimated PEL at SPL (from table/column in step 3 of the appendix): ___________________________

9. Duty Cycle Known: Yes _______ (do step 9); No _____ (stop)

   Adjusted PEL for actual duty cycle

   Actual DC % = 100 × ____ sec. (pulse length / ___ sec. (pulse repetition period)
   Actual DC % = ____
   Adjusted PEL = PEL (from step 8) ____ min. × 20 / actual duty cycle (%) ___ = ____ min.

   PEL1 = _____ minutes; PEL2 = _____ minutes

   Reminder: Do not adjust the PEL if duty cycle is unknown.

10. Multiple Sonars: Yes _____ (do step 10); No ____ (stop)

    Sonar 1: DT1 = ______ (Desired dive duration)

    PEL1 = _______ (from Step 8 or 9, as applicable)

    DT1/PEL1 = ____________ .

    Sonar 2: DT1 = ______ (Desired dive duration)

    PEL1 = ________ (from Step 8 or 9, as applicable)

    DT1/PEL1 = ____________ .

    ND = ______ + _______ = ________ (This is less than 1.0, so dive is acceptable and may proceed.)

    Reminder: The Noise Dose must not exceed a value of 1.0.

Figure 1A-1. Sonar Safe Diving Distance/Exposure Time Worksheet.

NOTE **Note: If range is between two values in the table, use the shorter range. This will insure that the SPL is not underestimated and that the PEL is conservative.**

Step 5. **Estimated SPL**. In the PEL selection table (Table 1A-1) determined in step 3 of the worksheet (Figure 1A-1), locate the diving distance (range) in the appropriate sonar equipment column. Read across to the leftmost column to find the SPL in dB. For ranges intermediate to those shown use the shorter range. Enter this SPL value in step 5 of the worksheet. If the SPL value in dB can be determined at the dive site, enter the measured SPL value in step 5.

Step 6. **Helmeted Dive Depth Reduction**.

If the diver dress is not helmeted, enter 0 in step 6 of the worksheet and go to step 7 of these instructions.

Helmeted divers experience reduced sensitivity to sound pressure as depth increases. The reductions listed in Table 1A-2 may be subtracted from the SPLs for helmeted divers in Table 1A-5. Enter the reduction in step 6 of the worksheet. If the depth is between two values in the table, use the lesser reduction since that value will produce a conservative PEL.

Table 1A-2. *Depth Reduction Table.*

Depth (FSW)	Reduction (dB)	Depth (FSW)	Reduction (dB)
9	1	98	6
19	2	132	7
33	3	175	8
50	4	229	9
71	5	297	10

Step 7. **Corrected SPL**. The corrected SPL equals the Estimated SPL from step 5 minus the reduction in dB from step 6. Enter the corrected SPL in step 7 of the worksheet.

Step 8. **PEL Determination**. Go to the SPL in the appropriate table and read one column right to find the PEL for the SPL shown in step 7 of the worksheet. Enter in step 8 of the worksheet.

Step 9. **Duty Cycle/Adjusted PEL Calculation**. Tables 1 A-3 through 1A-6 assume a transmit duty cycle of 20 percent. Duty cycle (DC) is the percentage of time in a given period that the water is being ensonified (sonar transmitting). Sonar operators may use various means of computing DC that are valid for the purpose of this instruction. If the actual duty cycle is different from 20 percent, PELs may be extended or shortened proportionally. Use step 9 of the worksheet to calculate and enter the corrected PEL.

The formula for duty cycle is:

DC = 100 × Pulse length (sec.) / Pulse Repetition Period (sec.)

The formula for the adjusted PEL is:

Adjusted PEL = PEL × 20 / actual duty cycle; **Equation 1**

Example Problem. An un-hooded wet suited diver is 16 yards from an AN/SQQ-14 sonar transmitting a 500 msec pulse (.5 seconds) every 10 seconds.

Solution. The actual duty cycle (DC) % is:

Actual DC % = 100 × .5 / 10 = 5 percent.

Locate the PEL from the table (which is for a 20% duty cycle). Compute the adjusted PEL as:

Using worksheet step 9, Adjusted PEL = PEL (from step 8) 170 × 20/5=680 minutes.

If variable duty cycles are to be used, select the greatest percent value.

Step 10. **Multiple Sonar/Noise Dose Calculation**. When two or more sonars are operating simultaneously, or two or more periods of noise exposure of different values occur, the combined effects must be considered. In the following formula, **ND is the daily noise dose and must not exceed a value of 1.0**, DT is the dive (exposure) time (left surface to reach surface), and PEL is the PEL for each noise exposure condition computed as described above:

ND = DT1/PEL1 + DT2/PEL2 + ... DTn/PELn; **Equation 2**

Note: DT1/PEL1 is for the first sonar, DT2/PEL2 is for the second sonar, up to the total number of sonars in use.

To use the worksheet, go through the steps 1-9 for each sonar, entering the appropriate values in each step of the worksheet. Enter the PELs into the worksheet step 10. There is room for two sonars in the worksheet. If more than two are being used, follow the same format and continue the calculations in the white space at the end of the worksheet.

Example Problem. A hooded wet suited diver is 100 yards from a transmitting AN/SQS-53A sonar and a transmitting AN/SQS-23 sonar for fifteen minutes.

Solution.
DT1 = 15 minutes

PEL1 (for SQS-53A) = 50 minutes
DT1/PEL1 = 15/50 = .3

DT2 = 15 minutes
PEL2 (for SQS-23) = 285 minutes
DT2/PEL2 = 15/285 = .05

ND = .3 + .05 = .35
This is less than 1.0 and therefore is acceptable.

Example 1: *You are planning a routine dive for 160 minutes using wet-suited divers without hoods at a dive site 17 yards from an AN/SQQ-14 sonar. The duty cycle for the AN/SQQ-14 sonar is unknown. Is this dive permitted? Provide justification for your decision.*

SONAR SAFE DIVING DISTANCE/EXPOSURE TIME WORKSHEET

1. Diver dress: Wet Suit - Un-hooded __X__
   Wet Suit - Hooded _____
   Helmeted ______

2. Type(s) of sonar: AN/SQQ-14

3. PEL Table 1A-3 __; 1A-4 __; 1A-5 __; 1A-6 _X_

4. Range(s) to sonar (yards): 17

5. Estimated SPL at range(s) in step 3 (from table/column in step 3): SPL = 198 dB

   Reminder: If range is between two values in the table, use the shorter range.
   If the SPL is measured at the dive site, use the measured value.

6. Depth Reduction __0__ dB

   Reminder: **0 if not helmeted, see table in instructions if helmeted**.

7. Corrected SPL (Step 5 minus Step 6) SPL1 198 – 0 = 198 dB

8. Estimated PEL at SPL (from table/column in step 3 of the appendix): PEL1 = 170 minutes

9. Duty Cycle Known: Yes ______ (do step 9); No __X__ (stop)
   Adjusted PEL for actual duty cycle
   Actual DC % = 100 × ______ sec. (pulse length / ______ sec. (pulse repetition period)
   Actual DC % = ______
   Adjusted PEL = PEL (from step 8) ___ min. × 20 / actual duty cycle (%) ___ = ___ min.

   Reminder: Do not adjust the PEL if duty cycle is unknown.

10. Multiple Sonars: Yes _____ (do step 10); No __X__ (stop)

    Sonar 1: DT1 = ____ (Desired dive duration)
    PEL1 = ____ (from Step 8 or 9, as applicable)
    DT1/PEL1 = _______ .

    Sonar 2: DT1 = ____ (Desired dive duration)
    PEL1 = ____ (from Step 8 or 9, as applicable)
    DT1/PEL1 = _______ .

    ND = ____ + _____ = ____ (This is less than 1.0, so dive is acceptable and may proceed.)

    Reminder: The Noise Dose must not exceed a value of 1.0.

The dive time of 160 minutes is permitted because the PEL is 171 minutes.

Figure 1A-2. Sonar Safe Diving Distance/Exposure Time Worksheet (Completed Example).

Example 2: *You are planning a routine dive for 75 minutes using wet-suited divers without hoods at a dive site which is 1000 yards from an AN/SQS-23 sonar. The SPL was measured at 185 dB. The duty cycle for the AN/SQS-23 sonar is unknown. Is this dive permitted? Provide justification for your decision.*

SONAR SAFE DIVING DISTANCE/EXPOSURE TIME WORKSHEET

1. Diver dress: Wet Suit - Un-hooded __X__
   Wet Suit - Hooded _____
   Helmeted ______

2. Type(s) of sonar: AN/SQS-23

3. PEL Table 1A-3 __X__; 1A-4 __; 1A-5 __; 1A-6 __

4. Range(s) to sonar (yards): 1000

5. Estimated SPL at range(s) in step 3 (from table/column in step 3): SPL = 185 dB

   Reminder: If range is between two values in the table, use the shorter range.
   If the SPL is measured at the dive site, use the measured value.

6. Depth Reduction __0__ dB

   Reminder: 0 if not helmeted, see table in instructions if helmeted.

7. Corrected SPL (Step 5 minus Step 6) SPL1 185 – 0 = 185 dB

8. Estimated PEL at SPL (from table/column in step 3 of the appendix): PEL1 = 170 minutes

9. Duty Cycle Known: Yes ______ (do step 9); No __X__ (stop)
   Adjusted PEL for actual duty cycle
   Actual DC % = 100 × ______ sec. (pulse length / ______ sec. (pulse repetition period)
   Actual DC % = ______
   Adjusted PEL = PEL (from step 8) ___ min. × 20 / actual duty cycle (%) ___ = ___ min.

   Reminder: Do not adjust the PEL if duty cycle is unknown.

10. Multiple Sonars: Yes _____ (do step 10); No __X__ (stop)

   Sonar 1: DT1 = ____ (Desired dive duration)
   PEL1 = ____ (from Step 8 or 9, as applicable)
   DT1/PEL1 = _______ .

   Sonar 2: DT1 = ____ (Desired dive duration)
   PEL1 = ____ (from Step 8 or 9, as applicable)
   DT1/PEL1 = _______ .

   ND = ____ + _____ = ____ (This is less than 1.0, so dive is acceptable and may proceed.)
   Reminder: The Noise Dose must not exceed a value of 1.0.

The dive time of 75 minutes is permitted because the PEL is 170 minutes.

Figure 1A-3. Sonar Safe Diving Distance/Exposure Time Worksheet (Completed Example).

Example 3: *You are planning a 98 fsw dive for 35 minutes using the MK 21 at a dive site which is 3000 yards from an AN/SQS-53C sonar. The duty cycle for the AN/SQS-53C sonar is unknown. Is this dive permitted? Provide justification for your decision.*

SONAR SAFE DIVING DISTANCE/EXPOSURE TIME WORKSHEET

1. Diver dress: Wet Suit - Un-hooded ______
   Wet Suit - Hooded _____
   Helmeted __X___

2. Type(s) of sonar: AN/SQS-53C

3. PEL Table 1A-3 ___; 1A-4 __; 1A-5 _X_ ; 1A-6 __

4. Range(s) to sonar (yards): 3000

5. Estimated SPL at range(s) in step 3 (from table/column in step 3): SPL1 = 181 dB

   Reminder: If range is between two values in the table, use the shorter range.
   If the SPL is measured at the dive site, use the measured value.

6. Depth Reduction __6___ dB

   Reminder: **0 if not helmeted, see table in instructions if helmeted**.

7. Corrected SPL (Step 5 minus Step 6) _SPL1 181 – 6 = 175 dB_

8. Estimated PEL at SPL (from table/column in step 3 of the appendix): PEL1 = 50 minutes

9. Duty Cycle Known: Yes ______ (do step 9); No __X__ (stop)
   Adjusted PEL for actual duty cycle
   Actual DC % = 100 × ______ sec. (pulse length / ______ sec. (pulse repetition period)
   Actual DC % = ______
   Adjusted PEL = PEL (from step 8) ___ min. × 20 / actual duty cycle (%) ___ = ___ min.

   Reminder: Do not adjust the PEL if duty cycle is unknown.

10. Multiple Sonars: Yes _____ (do step 10); No _X__ (stop)

    Sonar 1: DT1 = ____ (Desired dive duration)
    PEL1 = ____ (from Step 8 or 9, as applicable)
    DT1/PEL1 = _______ .

    Sonar 2: DT1 = ____ (Desired dive duration)
    PEL1 = ____ (from Step 8 or 9, as applicable)
    DT1/PEL1 = _______ .

    ND = ____ + _____ = ____ (This is less than 1.0, so dive is acceptable and may proceed.)
    Reminder: The Noise Dose must not exceed a value of 1.0.

The dive time of 35 minutes is permitted because the PEL is 50 minutes.

Figure 1A-4. Sonar Safe Diving Distance/Exposure Time Worksheet (Completed Example).

Example 4: *You are planning a routine dive for 120 minutes using wet-suited divers with hoods at a dive site which is 200 yards from an AN/SQS-53A sonar and 120 yards from an AN/SQS-23 sonar. The AN/SQS-53A sonar is transmitting an 800 msec pulse (0.8 sec) every 20 seconds. The duty cycle for the AN/SQS-23 sonar is unknown. Is this dive permitted? Provide justification for your decision.*

SONAR SAFE DIVING DISTANCE/EXPOSURE TIME WORKSHEET

1. Diver dress:
   Wet Suit - Un-hooded ______
   Wet Suit - Hooded __X__
   Helmeted _____

2. Type(s) of sonar: AN/SQS-53A and AN/SQS-23

3. PEL Table 1A-3 ___; 1A-4 _X_; 1A-5 ___ ; 1A-6 ___

4. Range(s) to sonar (yards): 200 (from SQS-53A); 120 (from SQS-23)

5. Estimated SPL at range(s) in step 3 (from table/column in step 3): SPL1 = 201; SPL2 = 196
   (per reminder, use SPL for 112 yard range)
   Reminder: If range is between two values in the table, use the shorter range.
   If the SPL is measured at the dive site, use the measured value.

6. Depth Reduction __0__ dB

   Reminder: **0 if not helmeted, see table in instructions if helmeted**.

7. Corrected SPL (Step 5 minus Step 6) SPL1 201 – 0 = 201 dB; SPL2 196 – 0 = 196 dB;

8. Estimated PEL at SPL (from table/column in step 3 of the appendix): PEL1 = 143 min; PEL 2 = 339 min

9. Duty Cycle Known: Yes __X__ (do step 9); No _____ (stop)
   Adjusted PEL for actual duty cycle
   Actual DC % = 100 × __0.8__ sec. (pulse length / __20__ sec. (pulse repetition period)
   Actual DC % = __4__
   Adjusted PEL = PEL (from step 8) 143 min. × 20 / actual duty cycle (%) _4_ = _715_ min.
   PEL1 = _715_ minutes; PEL2 = _339_ minutes
   Reminder: Do not adjust the PEL if duty cycle is unknown.

10. Multiple Sonars: Yes __X__ (do step 10); No ____ (stop)

    Sonar 1: DT1 = 120 (Desired dive duration)
    PEL1 = 715 (from Step 8 or 9, as applicable)
    DT1/PEL1 = 120/715 = 0.17 .

    Sonar 2: DT1 = 120 (Desired dive duration)
    PEL1 = 339 (from Step 8 or 9, as applicable)
    DT1/PEL1 = 120/339 = .35 .

    ND = 0.17 + 0.35 = 0.52 (This is less than 1.0, so dive is acceptable and may proceed.)
    Reminder: The Noise Dose must not exceed a value of 1.0.

The dive time of 120 minutes is permitted because the ND is less than 1.0.

Figure 1A-5. Sonar Safe Diving Distance/Exposure Time Worksheet (Completed Example).

__Table 1A-3.__ Wet Suit Un-Hooded.

Permissible Exposure Limit (PEL) within a 24-hour period for exposure to AN/SQS-23, -26, -53, -56, AN/BSY-1, -2 and AN/BQQ-5 sonars, including versions and upgrades. Exposure conditions shown above the double line should be avoided except in cases of compelling operational necessity.

Estimated Ranges in yards for given SPL and PEL for sonar.

SPL (dB)	**PEL (MIN)**	**BSY-1 SQS-53C**	**BQQ-5 BSY-2 SQS-26CX(U) SQS-53A, SQS-53B SQS-56(U)**	**SQS-23 SQS-26AX SQS-26BX, SQS-26CX SQS-56**		
200	13	316	224	71	**A**	
199	15	355	251	79	**V**	**E**
198	18	398	282	89	**O**	**X**
197	21	447	316	100	**I**	**P**
196	25	501	355	112	**D**	**O**
195	30	562	398	126		**S**
194	36	631	447	141	**T**	**U**
193	42	708	501	158	**H**	**R**
192	50	794	562	178	**I**	**E**
191	60	891	631	200	**S**	
190	71	1,000	708	224		
189	85	1,122	794	251		
188	101	1,259	891	282		
187	120	1,413	1,000	316		
186	143	1,585	1,122	355		
185	170	1,778	1,259	398		
184	202	1,995	1,413	447		
183	240	2,239	1,585	501		
182	285	2,512	1,778	562		
181	339	2,818	1,995	631		
180	404	3,162	2,239	708		
179	480	3,548	2,512	794		
178	571	3,981	2,818	891		
177	679	4,467	3,162	1,000		
176	807	5,012	3,548	1,122		
175	960	5,623	3,981	1,259		

All ranges and SPLs are nominal.

*SPL is measured in dB/1 μPA at the dive site. To convert SPL for sound levels referenced to mbar, subtract 100 dB from tabled levels.

(U) = upgrade

Table 1A-4. *Wet Suit Hooded.*

Permissible Exposure Limit (PEL) within a 24-hour period for exposure to AN/SQS-23, -26, -53, -56, AN/BSY-1, -2, and AN/BQQ-5 sonar, including versions and upgrades. Exposure conditions shown above the double line should be avoided except in cases of compelling operational necessity.

Estimated Ranges in yards for given SPL and PEL for sonar.

SPL (dB)	**PEL (MIN)**	**BSY-1 SQS-53C**	**BQQ-5 BSY-2 SQS-26CX(U) SQS-53A, SQS-53B SQS-56(U)**	**SQS-23 SQS-26AX SQS-26BX, SQS-26CX SQS-56**		
215	13	56	40	13	**A**	
214	15	63	45	14	**V**	**E**
213	18	71	50	16	**O**	**X**
212	21	79	56	18	**I**	**P**
211	25	89	63	20	**D**	**O**
210	30	100	71	22		**S**
209	36	112	79	25	**T**	**U**
208	42	126	89	28	**H**	**R**
207	50	141	100	32	**I**	**E**
206	60	158	112	35	**S**	
205	71	178	126	40		
204	85	200	141	45		
203	101	224	158	50		
202	120	251	178	56		
201	143	282	200	63		
200	170	316	224	71		
199	202	355	251	79		
198	240	398	282	89		
197	285	447	316	100		
196	339	501	355	112		
195	404	562	398	126		
194	480	631	447	141		
193	571	708	501	158		
192	679	794	562	178		
191	807	891	631	200		
190	960	1,000	708	224		

All ranges and SPLs are nominal.

*SPL is measured in dB/1 μPA at the dive site. To convert SPL for sound levels referenced to mbar, subtract 100 dB from tabled levels.

(U) = upgrade

Table 1A-5. *Helmeted.*

Permissible Exposure Limit (PEL) within a 24-hour period for exposure to AN/SQS-23, -26, -53, -56, AN/BSY-1, -2, and AN/BQQ-5 sonar, including versions and upgrades. Exposure conditions shown above the double line should be avoided except in cases of compelling operational necessity.

Estimated Ranges in yards for given SPL and PEL for sonar.

SPL (dB)	PEL (MIN)	BSY-1 SQS-53C	BQQ-5 BSY-2 SQS-26CX(U) SQS-53A, SQS-53B SQS-56(U)	SQS-23 SQS-26AX SQS-26BX, SQS-26CX SQS-56		
183	13	2,239	1,585	501	A	
182	15	2,512	1,778	562	V	E
181	18	2,818	1,995	631	O	X
180	21	3,162	2,239	708	I	P
179	25	3,548	2,512	794	D	O
178	30	3,981	2,818	891		S
177	36	4,467	3,162	1,000	T	U
176	42	5,012	3,548	1,122	H	R
175	50	5,623	3,981	1,259	I	E
174	60	6,310	4,467	1,413	S	
173	71	7,079	5,012	1,585		
172	85	7,943	5,623	1,778		
171	101	8,913	6,310	1,995		
170	120	10,000	7,079	2,239		
169	143	11,220	7,943	2,512		
168	170	12,589	8,913	2,818		
167	202	14,125	10,000	3,162		
166	240	15,849	11,220	3,548		
165	285	17,783	12,589	3,981		
164	339	19,953	14,125	4,467		
163	404	22,387	15,849	5,012		
162	480	25,119	17,783	5,623		
161	571	28,184	19,953	6,310		
160	679	31,623	22,387	7,079		
159	807	35,481	25,119	7,943		
158	960	39,811	28,184	8,913		

All ranges and SPLs are nominal.

*SPL is measured in dB/1 μPA at the dive site. To convert SPL for sound levels referenced to mbar, subtract 100 dB from tabled levels.

(U) = upgrade

Table 1A-6. *Permissible Exposure Limit (PEL) Within a 24-hour Period for Exposure to AN/SQQ-14, -30, -32 Sonars.*

Estimated Ranges in yards for given SPL and PEL for sonar.

WET SUIT UN-HOODED		
SPL (dB)	**PEL (MIN)**	**Range (yards)**
200	120	13
199	143	14
198	170	16
197	202	18
196	240	20
195	285	22
194	339	25
193	404	28
192	480	32
191	571	35
190	679	40
189	807	45
188	960	50

WET SUIT HOODED		
SPL (dB)	**PEL (MIN)**	**Range (yards)**
215	120	2
214	143	3
213	170	3
212	202	3
211	240	4
210	285	4
209	339	4
208	404	5
207	480	6
206	571	6
205	679	7
204	807	8
203	960	9

Dry suit helmeted divers: no restriction for these sonars. All ranges and SPLs are nominal.

*SPL is measured in dB/1 μPA at the dive site. To convert SPL for sound levels referenced to mbar, subtract 100 dB from tabled levels.

1A-5 GUIDANCE FOR DIVER EXPOSURE TO LOW-FREQUENCY SONAR (160–320 Hz)

If possible, you should avoid diving in the vicinity of low-frequency sonar (LFS). LFS generates a dense, high-energy pulse of sound that can be harmful at higher power levels. Because a variety of sensations may result from exposure to LFS, it is necessary to inform divers when exposure is likely and to brief them regarding possible effects; specifically, that they can expect to hear and feel it. Sensations may include mild dizziness or vertigo, skin tingling, vibratory sensations in the throat and abdominal fullness. Divers should also be briefed that voice communications are likely to be affected by the underwater sound to the extent that line pulls or other forms of communication may become necessary. Annoyance and effects on communication are less likely when divers are wearing a hard helmet (MK 21) diving rig. For safe distance guidance, contact NAVSEA (00C3). Telephone numbers are listed in Volume 1, Appendix C.

1A-6 GUIDANCE FOR DIVER EXPOSURE TO ULTRASONIC SONAR (250 KHz AND GREATER)

The frequencies used in ultrasonic sonars are above the human hearing threshold. The primary effect of ultrasonic sonar is heating. Because the power of ultrasonic sonar rapidly falls off with distance, a safe operating distance is 10 yards or greater. Dive operations may be conducted around this type of sonar provided that the diver does not stay within the sonar's focus beam. The diver may finger touch the transducer's head momentarily to verify its operation as long as the sonar is approached from the side.

APPENDIX 1B

References

References	Subject
BUMEDINST 6320.38	Clinical Use of Recompression Chambers for Non-Diving Illnesses: Policy for
Manual of the Medical Department, Article 15-66	Medical Examinations
MILPERSMAN Article 1220	Military Personnel Manual
NAVEDTRA 10669-C	Hospital Corpsman 3 & 2
NAVFAC P-990	UCT Conventional Inspection and Repair Techniques
NAVFAC P-991	Expedient Underwater Repair Techniques
NAVFAC P-992	UCT Arctic Operations Manual
NAVMEDCOMINST 6200.15	Suspension of Diving During Pregnancy
NAVMED P-5010	Manual of Naval Preventive Medicine
NAVSEA 10560 ltr, Ser 00C34/3160 of 27 Sept 01	UBA Canister Duration
NAVSEA/00C ANU, www.navsea.navy.mil/sea00c/doc/anu_disc.html	Authorized for Navy Use
NAVSEA (SS521-AA-MAN-010)	U.S. Navy Diving and Manned Hyperbaric System Safety Certification Manual
NAVSEA Technical Manual (S0600-AA-PRO-010)	Underwater Ship Husbandry Manual
NAVSEA Technical Manual (SS500-HK-MMO-010)	MK 3 MOD 0 Light Weight Diving System Operating and Maintenance
NAVSEA Technical Manual (SS500-AW-MMM-010)	MK 6 MOD 0 Transportable Recompression Chamber System Operating and Maintenance
NAVSEA Technical Manual (SS600-AA-MMA-010)	MK 16 MOD 0 Operating and Maintenance
NAVSEA Technical Manual (SS600-AQ-MMO-010)	MK 16 MOD 1 Operating and Maintenance
NAVSEA Technical Manual (SS-600-A3-MMO-010)	MK 25 MOD 2 UBA Operating and Maintenance
NAVSEA Technical Manual (S9592-B1-MMO-010)	Fly Away Dive System (FADS) III Air System Operating and Maintenance
NAVSEA Technical Manual (SS9592-B2-MMO-010)	Fly Away Dive System (FADS) III Mixed Gas System (FMGS) Operating and Maintenance
NAVSEA Technical Manual (S9592-AN-MMO-010)	Emergency Breathing System Type I Operating and Maintenance
NAVSEA Technical Manual (0938-LP-011-4010)	Nuclear Powered Submarine Atmosphere Control Manual
NAVSEA Technical Manual (S9592-AY-MMO-020)	MK 5 MOD 0 Flyaway Recompression Chamber (FARCC)
NAVSEA Technical Manual (SS500-B1-MMO-010)	Standard Navy Double-Lock Recompression Chamber System

NAVSEA Technical Manual (SH700-A2-MMC-010)	Emergency Hyperbaric Stretcher Operations and Maintenance
NAVSEA Technical Manual (SS521-AJ-PRO-010)	Guidance for Diving in Contaminated Waters
Naval Ships Technical Manual, Chapter 74, Vol. 1 (S9086-CH-STM-010)	Welding and Allied Processes
Naval Ships Technical Manual, Chapter 74, Vol. 3 (S9086-CH-STM-030)	Gas Free Engineering
Naval Ships Technical Manual, Chapter 262 (S9086-H7-STM-010)	Lubricating Oils, Greases, Specialty Lubricants, and Lubrication Systems
Naval Ships Technical Manual, Chapter 550 (S9086-SX-STM-010)	Industrial Gases, Generating, Handling, and Storage
NAVSEA Operation & Maintenance Instruction (0910-LP-001-6300)	Fly Away Diving System Filter/Console
NAVSEA Operation & Maintenance Instruction (0910-LP-001-1500)	Fly Away Diving System Diesel Driven Compressor Unit EX 32 MOD 0, PN 5020559
Naval Safety Center Technical Manual	Guide to Extreme Cold Weather
NAVSEA Technical Manual (S0300-A5-MAN-010)	Polar Operations Manual
Office of Naval Research Technical Manual	Guide to Polar Diving
ASTM G-88-90	Standard Guide for Designing Systems for Oxygen Service
ASTM G-63-92	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM G-94-92	Standard Guide for Evaluating Metals for Oxygen Service
FED SPEC BB-A-1034 B	Diver's Compressed Air Breathing Standard
FED SPEC A-A-59503	Compressed Nitrogen Standard
MIL-D -16791	Detergents, General Purpose (Liquid, Nonionic)
MIL-PRF-27210G	Oxygen, Aviators Breathing, Liquid and Gaseous
MIL-PRF-27407B	Propellant Pressurizing Agent Helium, Type I Gaseous Grade B
MIL-STD-438	Schedule of Piping, Valves and Fittings, and Associated Piping Components for Submarine Service
MIL-STD-777	Schedule of Piping, Valves and Fittings, and Associated Piping Components for Naval Surface Ships
MIL-STD-1330	Cleaning and Testing of Shipboard Oxygen, and Nitrogen Systems Helium, Helium - Oxygen
OPNAVINST 3120.32C CH-1	Equipment Tag-Out Bill
OPNAVINST 3150.27 Series	Navy Diving Program
OPNAVINST 5100.19C, Appendix A-6	Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat
OPNAVINST 5100.23	Navy Occupational Safety and Health (NAVOSH) Afloat Program Manual
OPNAVINST 5102.1C CH-1	Mishap Investigation and Reporting
OPNAVINST 8023.2C CH-1	U.S. Navy Explosives Safety Policies, Requirements, and Procedures (Department of the Navy Explosives Safety Policy Manual)
OSHA 29 CFR Part 1910 Subpart T, PG 6-36	Commercial Diving Opearations

MIL-L-17331	Lubricant (2190 TEP)
MIL-H-17672	Lubricant (2135 TH)
ANSI-B57.1 and CSA-B96	American and Canadian Standard Compressed-Gas Cylinder Valve Outlet and Inlet Connections
Z48.1	American National Standard Method of Marking Portable Compressed-Gas Containers to Identify the Material Contained
CGA Pamphlet C-7	Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Cylinders

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APPENDIX 1C
Telephone Numbers

Command	Department	Telephone	Fax
Naval Surface Warfare Center - Panama City, Florida (NSWC-PC)	Diver Life Support (Fleet Support & Air Sampling	(850) 234-4482 DSN: 436-4482	(850) 234-4775
BUMED M3F7		(202) 762-3444	
National Oceanic and Atmospheric Administration (NOAA)	HAZMAT	(206) 526-6317	(206) 526-6329
Naval Sea Systems Command (COMNAVSEASYSCOM) 00C 00C1 00C2 00C3 00C4 00C5	 Director Finance Salvage Diving Certification Husbandry	(202) 781-XXXX DSN: 326-XXXX (202) 781-0731 (202) 781-0648 (202) 781-2736 (202) 781-0934 (202) 781-0927 (202) 781-0534	(202) 781-4588
Naval Sea Systems Command Code 07Q	Deep Submergence Systems Certification	(202) 781-1467 (202) 781-1336	
Naval Facilities Engineering Command (NAVFAC)	Chief Engineer (Code CHENG)	Comm: (202) 685-9165 DSN: 325-9165	(202) 685-1577
NAVFAC Ocean Facilities Program	(Code OFP)	(202) 433-5596 DSN 288-5596.	(202) 433-2280

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APPENDIX 1D

List of Acronyms

ABS	Acrylonitrile Butadiene Styrene
ACF	Actual Cubic Feet
ACFM	Actual Cubic Feet per Minute
ACGIH	American Conference of Governmental Industrial Hygienists
ACLS	Advanced Cardiac Life Support
ADS	Advance Diving System
AGE	Arterial Gas Embolism
ALSS	Auxiliary Life-Support System
AM	Amplitude Modulated
ANU	Authorized for Navy Use List
AQD	Additional Qualification Designator
ARD	Audible Recall Device
ARS	Auxiliary Rescue/Salvage Ship
AS	Submarine Tender
ASDS	Advanced SEAL Delivery System
ASRA	Air Supply Rack Assembly
ASME	American Society of Mechanical Engineers
ATA	Atmosphere Absolute
ATP	Ambient Temperature and Pressure
ATS	Active Thermal System
BC	Buoyancy Compensator
BCLS	Basic Cardiac Life Support
BIBS	Built-In Breathing System

BPM	Breaths per Minute
BTPS	Body Temperature, Ambient Pressure
BTU	British Thermal Unit
CDO	Command Duty Officer
CCTV	Closed-Circuit Television
CGA	Compressed Gas Association
CNO	Chief of Naval Operations
CNS	Central Nervous System
CONUS	Continental United States
COSAL	Coordinated Shipboard Allowance List
CPR	Cardiopulmonary Resuscitation
CRS	Chamber Reducing Station
CSMD	Combat Swimmer Multilevel Dive
CUMA	Canadian Underwater Minecountermeasures Apparatus
CWDS	Contaminated Water Diving System
DATPS	Divers Active Thermal Protection System
DC	Duty Cycle
DCS	Decompression Sickness
DDC	Deck Decompression Chamber
DDS	Deep Diving System
DDS	Dry Deck Shelter
DHMLS	Divers Helmet Mounted Lighting System
DLSE	Diving Life-Support Equipment
DLSS	Divers Life Support System
DMO	Diving Medical Officer

DMS	Dive Monitoring System
DMT	Diving Medical Technician
DOT	Department of Transportation
DRS	Dive Reporting System
DSI	Diving Systems International
DSM	Diving System Module
DSRG	Deep Submergence Review Group
DSRV	Deep Submergence Rescue Vehicle
DSSP	Deep Submergence System Project
DT	Dive Time *or* Descent Time
DT/DG	Dive Timer/Depth Gauge
DUCTS	Divers Underwater Color Television System
DV	Diver
DPV	Diver Propulsion Vehicle
EAD	Equivalent Air Depth
EBA	Emergency Breathing Apparatus
EBS I	Emergency Breathing System I
EDWS	Enhanced Diver Warning System
EEHS	Emergency Evacuation Hyperbaric Stretcher
EGS	Emergency Gas Supply
ENT	Ear, Nose, and Throat
EOD	Explosive Ordnance Disposal
EPs	Emergency Procedures
ESDS	Enclosed Space Diving System
ESDT	Equivalent Single Dive Time

ESSM	Emergency Ship Salvage Material
FADS III	Flyaway Air Dive System III
FAR	Failure Analysis Report
FARCC	Flyaway Recompression Chamber
FED SPEC	Federal Specifications
FFM	Full Face Mask
FFW	Feet of Fresh Water
FMGS	Flyaway Mixed-Gas System
FPM	Feet per Minute
FSW	Feet of Sea Water
FV	Floodable Volume
GFI	Ground Fault Interrupter
GPM	Gallons per Minute
HBO_2	Hyperbaric Oxygen
HOSRA	Helium-Oxygen Supply Rack Assembly
HP	High Pressure
HPNS	High Pressure Nervous Syndrome
HSU	Helium Speech Unscrambler
ICCP	Impressed-Current Cathodic Protection
IDV	Integrated Divers Vest
IL	Inner Lock
ILS	Integrated Logistics Support
ISIC	Immediate Senior in Command
JAG	Judge Advocate General
J/L	Joules per Liter, Unit of Measure for Work of Breathing
KwHr	Kilowatt Hour

LB	Left Bottom
LCM	Landing Craft, Medium
LFA	Low Frequency Acoustic
LFS	Low Frequency Sonar
LP	Low Pressure
LPM	Liters per Minute
LS	Left Surface
LSS	Life Support System *or* Life Support Skid
LWDS	Light Weight Diving System
MBC	Maximal Breathing Capacity
MCC	Main Control Console
MD	Maximum Depth
MDSU	Mobile Diving and Salvage Unit
MDV	Master Diver
MEFR	Maximum Expiratory Flow Rate
MEV	Manual Exhaust Valve
MFP	Minimum Flask Pressure
MGCCA	Mixed-Gas Control Console Assembly
MIFR	Maximum Inspiratory Flow Rate
MIL-STD	Military Standard
MMP	Minimum Manifold Pressure
MP	Medium Pressure
MRC	Maintenance Requirement Card
MSW	Meters of Sea Water
MVV	Maximum Ventilatory Volume

NAVEDTRA	Naval Education Training
NAVFAC	Naval Facilities Engineer Command
NAVMED	Naval Medical Command
NAVSEA	Naval Sea Systems Command
ND	Noise Dose
NDSTC	Naval Diving and Salvage Training Center
NEC	Navy Enlisted Classification
NEDU	Navy Experimental Diving Unit
NEURO	Neurological Examination
NID	Non-Ionic Detergent
NITROX	Nitrogen-Oxygen
NMRI	Navy Medical Research Institute
NOAA	National Oceanic and Atmospheric Administration
NO-D	No Decompression
NPC	Naval Personnel Command
NRV	Non Return Valve
NSMRL	Navy Submarine Medical Research Laboratory
NSN	National Stock Number
NSTM	Naval Ships Technical Manual *or* NAVSEA Technical Manual
NSWC-PC	Naval Surface Warfare Center - Panama City
O&M	Operating and Maintenance
OBP	Over Bottom Pressure
OCEI	Ocean Construction Equipment Inventory
OIC	Officer in Charge
OJT	On the Job Training
OL	Outer Lock

OOD	Officer of the Deck
OPs	Operating Procedures
OSF	Ocean Simulation Facility
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PMS	Planned Maintenance System
PNS	Peripheral Nervous System
PP	Partial Pressure
$PPCO_2$	Partial Pressure Carbon Dioxide
PPM	Parts per Million
PPO_2	Partial Pressure Oxygen
PSI	Pounds per Square Inch
PSIA	Pounds per Square Inch Absolute
PSIG	Pounds per Square Inch Gauge
PSOB	Pre-Survey Outline Booklet
PTC	Personnel Transfer Capsule
PTS	Passive Thermal System
QA	Quality Assurance
RB	Reached Bottom
RCC	Recompression Chamber
REC	Re-Entry Control
RMV	Respiratory Minute Ventilation
RNT	Residual Nitrogen Time
ROV	Remotely Operated Vehicle
RQ	Respiratory Quotient

RS	Reached Surface
RSP	Render Safe Procedure
SAD	Safe Ascent Depth
SCA	System Certification Authority
SCF	Standard Cubic Feet
SCFM	Standard Cubic Feet per Minute
SCFR	Standard Cubic Feet Required
SCSCs	System Certification Survey Cards
SCUBA	Self Contained Underwater Breathing Apparatus
SDRW	Sonar Dome Rubber Window
SDS	Saturation Diving System
SDV	SEAL Delivery Vehicle
SEAL	Sea, Air, and Land
SET	Surface Equivalent Table
SEV	Surface Equivalent (percent or pressure)
SI	Surface Interval *or* System International
SLED	Sea Level Equivalent Depth
SLM	Standard Liters per Minute (short version used in formulas)
SLPM	Standard Liters per Minute
SNDB	Standard Navy Dive Boat
SOC	Scope of Certifications
SPL	Sound Pressure Level
SRDRS	Submarine Rescue and Diver Recompression System
SSB	Single Side Band
SSDS	Surface Supplied Diving System

STEL	Safe Thermal Exposure Limits
STP	Standard Temperature and Pressure
STPD	Standard Temperature and Pressure, Dry Gas
SUR D	Surface Decompression
SUR D AIR	Surface Decompression Using Air
SUR D O2	Surface Decompression Using Oxygen
T-ATF	Fleet Ocean Tug
TBT	Total Bottom Time
TDCS	Tethered Diver Communication System
TDT	Total Decompression Time
TL	Transfer Lock
TLC	Total Lung Capacity
TLD	Thermal Luminescence Dosimeter
TLV	Threshold Limit Values
TM	Technical Manual
TMDER	Technical Manual Deficiency Evaluation Report
TRC	Transportable Recompression Chamber
TRCS	Transportable Recompression Chamber System
TTD	Total Time of Dive
UBA	Underwater Breathing Apparatus
UCT	Underwater Construction Team
UDM	Underwater Decompression Monitor
UQC	Underwater Sound Communications
UWSH	Underwater Ship Husbandry
VENTIDC	Vision Ear Nausea Twitching Irritability Dizziness Convulsions
VTA	Volume Tank Assembly

VVDS	Variable Volume Dry Suit
WOB	Work of Breathing
YDT	Diving Tender

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CHAPTER 6

Operational Planning and Risk Management

6-1 INTRODUCTION

6-1.1 **Purpose.** Diving operations are inherently risky. This chapter provides a general guide for planning diving operations. All Naval activities shall apply the Operational Risk Management (ORM) process in planning operations and training to optimize operational capability and readiness in accordance with OPNAV INSTRUCTION 3500.39 (series). Correct application of these techniques will reduce mishaps and associated costs resulting in more efficient use of resources. ORM is a decision making tool used by personnel at all levels to increase operational effectiveness by identifying, assessing, and managing risks. Proper application of ORM minimizes risks to acceptable levels, commensurate with mission accomplishment. The amount of risk we will accept in war is much greater than that we should accept in peace, but the ORM process remains the same.

6-1.2 **Scope.** This chapter outlines a comprehensive planning process to effectively plan and execute diving operations in support of military operations. The planning worksheets and checklists contained in this chapter are examples of U.S. Navy material. They may be used as provided or modified locally to suit specific needs.

6-2 MISSION OBJECTIVE AND OPERATIONAL TASKS

A clear and concise statement of the mission objective shall be established. If the officer planning the operation is unclear about the urgency of the mission objective, he or she shall obtain clarification from the tasking authority to determine acceptable risks.

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

This section outlines the primary diving functions that may be identified in an operational task. These functions may be incorporated singly or in conjunction with others. Each task shall be identified and placed in the context of an overall schedule or job profile. Work items that must be coordinated with other support teams shall also be identified. The availability of outside assistance, including assistance for possible emergencies, from a diving unit or other sources must be coordinated in advance.

6-2.1 **Underwater Ship Husbandry (UWSH).** UWSH is the inspection, maintenance, and repair of Navy hulls and hull appendages while the hulls are waterborne.

Figure 6-1. Underwater Ship Husbandry Diving.

UWSH includes tasks such as patching, plugging, attaching cofferdams, waterborne hull cleaning, underwater weld repair to ship's hulls and appendages, propeller replacement, underwater hull inspection, and nondestructive testing (Figure 6-1).

6-2.1.1 **Objective of UWSH Operations.** The objective of all UWSH operations is to provide a permanent repair without dry-docking the ship. When a permanent repair is not possible, temporary repairs are performed to allow the ship to operate until its next scheduled drydocking where permanent repairs can be accomplished.

6-2.1.2 **Repair Requirements.** All UWSH repairs shall follow strict Quality Assurance (QA) procedures to ensure underwater systems are properly repaired. Divers shall work closely with all other repair activities to ensure procedures comply with prescribed ship design and maintenance specifications. All relevant technical manuals shall be made available for dive planning, and individual diver background and expertise shall be considered when assembling dive teams. The *NAVSEA Underwater Ship Husbandry Manual* (S0600-AA-PRO-010) provides general guidance and specific procedures to accomplish many underwater repairs.

6-2.1.3 **Diver Training and Qualification Requirements.** Many UWSH training requirements and qualifications are task specific. General training may be accomplished by:

- Formalized instruction as in First or Second Class Dive School
- NAVSEA-sponsored training, e.g., Sonar Dome Rubber Window (SDRW) Repair
- On the Job Training (OJT)
- Personnel Qualification Standards (PQS)

6-2.1.4 **Training Program Requirements.** A proper training program should result in permanent repairs meeting the same tolerances and QA requirements as if performed in dry-dock. 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 00C5.

6-2.2 Salvage/Object Recovery. In a salvage or object-recovery operation, divers work to recover sunken or wrecked naval craft, submersibles, downed aircraft, human remains, or critical items of equipment to help determine the cause of a mishap. Salvaged items may include classified or sensitive materials (Figure 6-2).

6-2.3 Search Missions. Underwater searches are conducted to locate 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, this type of search operation should incorporate the use of sidescan sonar and other search equipment whenever possible. 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 that can save in-water time and identify any special hazards of the dive mission.

6-2.4 Explosive Ordnance Disposal. Divers perform Explosive Ordnance Disposal tasks including recovering, identifying, disarming, and disposing of explosive devices that must be cleared from harbors, ships, and sea-lanes (Figure 6-3). Diving in the vicinity of ordnance combines the risks of diving and the explosive hazards of the ordnance. EOD divers shall accomplish diving to investigate, render safe, or dispose of explosive ordnance found underwater, regardless of type or fusing. Refer to Chapter 18 for more information on EOD operations.

6-2.5 Security Swims. Security swims are employed to search for underwater explosives or other devices that may have been attached to ships or piers. All qualified divers may conduct ship security swims. Once a task is identified as involving ordnance disposal, the area shall be marked. If EOD qualified personnel are not on site they shall be requested. Only EOD personnel may attempt to handle or dispose of underwater explosives or other devices as determined by the on-scene commander.

6-2.6 Underwater Construction. Underwater construction is 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. Pipelines, cables, sensor systems, and fixed/advanced-base structures are examples of in-water facilities (Figure 6-4).

6-2.6.1 **Diver Training and Qualification Requirements.** Seabee divers are specifically trained in the special techniques used to accomplish underwater construction tasks.

Figure 6-2. Salvage Diving. Surface-supplied divers on an aircraft recovery mission.

Figure 6-3. Explosive Ordnance Disposal Diving. An EOD diver using handheld sonar to locate objects underwater.

6-2.6.2 **Equipment Requirements.** Tools and equipment used include common underwater tools in addition to 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. Julian Creek, Norfolk, Virginia.

6-2.6.3 **Underwater Construction Planning Resources.** References for underwater construction planning can be found in:

- *UCT Conventional Inspection and Repair Techniques Manual* NAVFAC P-990
- *Expedient Underwater Repair Techniques* NAVFAC P-991
- *UCT Arctic Operations Manual* NAVFAC P-992
- *Design and Installation of Near-shore Ocean Cable Protection Systems* FPO-5-78

For more information on ocean construction, commands should consult NAVFAC Ocean Facilities Program.

Figure 6-4. Underwater Construction Diving.

6-2.7 **Demolition Missions.** Diving operations may include demolition duties to remove man-made structures such as barriers, sunken naval craft, and damaged piers. Blasting, freeing, flattening, or cutting with explosives define demolition operations. Divers may also be assigned to destroy natural formations, such as reefs, bars, and rock structures that interfere with transportation routes. All personnel involved in handling explosives shall be qualified in accordance with the OPNAVINST 8023.2 series.

6-2.8 **Combat Swimmer Missions.** Combat swimmers conduct 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 warfare objectives.

6-2.9 **Enclosed Space Diving.** Divers are often required to work in enclosed or confined spaces. Using surface-supplied Underwater Breathing Apparatus (UBA) (MK 20 MOD 0, MK 21 MOD 1, or EXO BR MS), divers may enter submarine ballast tanks, mud tanks, 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 shall be supported by a surface-supplied air system. Refer to Section 8-11.4 for more information on the hazards of enclosed space diving.

6-3 GENERAL PLANNING AND ORM PROCESS

A successful diving mission is the direct outcome of careful, thorough planning. The nature of each operation determines the scope of the planning effort, but certain general considerations apply to every operation.

- Bottom Time. Bottom time is always at a premium. Developing measures to conserve bottom time or increase diver effectiveness is critical for success.
- Preplanning. An operation that is delayed due to unanticipated problems may fail. Preplanning the use of the time available to accomplish specific objectives is a prerequisite to success.
- Equipment. Selecting the correct equipment for the job is critical to success.
- Environmental Conditions. Diving operational planners must plan for safely mitigating extreme environmental conditions. Personnel and support facility safety shall be given the highest priority.
- Diver Protection. It is critical to protect divers from shipping hazards, temperature extremes, and dangerous pollution during all operations.
- Emergency Assistance. It is critical to coordinate emergency assistance from outside sources before the operation begins.
- Weather. Because diving operations are weather dependent, dive planning shall allow for worst-case scenarios.

6-3.1 Concept of ORM:

- ORM is a decision making tool used by people at all levels to increase operational effectiveness by anticipating hazards and reducing the potential for loss, thereby increasing the probability of successful mission.
- Increases our ability to make informed decisions by providing the best baseline of knowledge and experience available.
- Minimizes risks to acceptable levels, commensurate with mission accomplishment. The amount of risk we will take in war is much greater than that we should be willing to take in peace, but the process is the same. Applying the ORM process will reduce mishaps, lower costs, and provide for more efficient use of resources.

6-3.2 Risk Management Terms:

- Hazard – A condition with potential to cause personal injury or death, property damage or mission degradation.
- Risk – An expression of possible loss in terms of severity and probability.
- Risk Assessment – The process of detecting hazards and assessing associated risks.
- ORM – The process of dealing with risk associated within military operations, which includes risk assessment, risk decision-making and implementation of effective risk controls.

6-3.3 ORM Process.

The five step process is:

1. Identify Hazards – Begin with an outline or chart of the major steps in the operation (operational analysis). Next, conduct a Preliminary Hazard Analysis by listing all of the hazards associated with each step in the operational analysis along with possible causes for those hazards.

2. Assess Hazards – For each hazard identified, determine the associated degree of risk in terms of probability and severity. Although not required; the use of a matrix may be helpful in assessing hazards.

3. Make Risk Decisions – First, develop risk control options. Start with the most serious risk first and select controls that will reduce the risk to a minimum consistent with mission accomplishment. With selected controls in place, decide if the benefit of the operation outweighs the risk. If risk outweighs benefit or if assistance is required to implement controls, communicate with higher authority in the chain of command.

4. Implement Controls – The following measures can be used to eliminate hazards or reduce the degree of risk. These are listed by order of preference:

   - Administrative Controls – Controls that reduce risks through specific administrative actions, such as:
   - Providing suitable warnings, markings, placards, signs, and notices.
   - Establishing written policies, programs, instructions and standard operating procedures (SOP).
   - Training personnel to recognize hazards and take appropriate precautionary measures.
   - Limiting the exposure to hazard (either by reducing the number or personnel/assets or the length of time they are exposed).
   - Engineering Controls – Controls that use engineering methods to reduce risks by design, material selection or substitution when technically or economically feasible.
   - Personal Protective Equipment – Serves as a barrier between personnel and hazard. It should be used when other controls do not reduce the hazard to an acceptable level.

5. Supervise – conduct follow-up evaluations of the controls to ensure they remain in place and have the desired effect. Monitor for changes, which may require further ORM. Take corrective action when necessary.

6-4 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 the need for any special emergency procedures

6-4.1 **Information Gathering.** The size of the operation, the diving site location, and the prevailing environmental conditions influence the extent and type of information that must be gathered when planning an operation. Some operations are of a recurring nature; so much of the required information is readily available. An example of a recurring operation is removing 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, requiring a change in procedure or special tools. Potential changes in task requirements affecting work procedures should not be overlooked during planning.

6-4.2 **Planning Data.** Many operations require that detailed information be collected in advance. For example, when planning to salvage 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. Such information can be obtained from ship's plans, cargo manifests and loading plans, interviews with witnesses and survivors, photographs, and official reports of similar accidents.

6-4.3 **Object Recovery.** Operations involving the recovery of an object from the bottom require knowledge of 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 determine 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 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.

6-4.3.1 **Searching for Objects or Underwater Sites.** When the operation involves searching for an object or underwater site, data gathered in advance helps to limit the search area. There are numerous planning data sources available to help supervisors collect data for the operation (see Figure 6-5).

For example, information useful in narrowing the search area for a lost aircraft includes the aircraft's last known heading, altitude, and speed; radar tracks plotted by ships and shore stations; tape recordings and radio transmissions; and eyewitness accounts. Once a general area is outlined, a side scan sonar system can be

PLANNING DATA SOURCES		
■ Aircraft Drawings ■ Cargo Manifest ■ Coastal Pilot Publications ■ Cognizant Command ■ Communications Logs ■ Construction Drawings ■ Current Tables ■ Diving Advisory Messages ■ DRT Tracks ■ DSV/DSRV Observations ■ Electronic Analysis ■ Equipment Operating Procedures (OPs) ■ Equipment Operation and Maintenance Manuals ■ Eyewitnesses ■ Flight or Ship Records ■ Flight Plan ■ Hydrographic Publications	■ Light Lists ■ Local Yachtsmen/Fishermen ■ LORAN Readings ■ Magnetometer Plots ■ Navigation Text (Dutton's/Bowditch) ■ Navigational Charts ■ NAVOCEANO Data ■ Notices to Mariners ■ OPORDERS ■ Photographs ■ Radar Range and Bearings ■ RDF Bearings ■ ROV Video and Pictures ■ Sailing Directions ■ Salvage Computer Data ■ Ship's Curves of Forms ■ Ship's Equipment ■ Ship's Logs and Records	■ Ship's Personnel ■ Ships Drawings (including docking plan) ■ Side-Scan Sonar Plots ■ SINS Records ■ SITREP ■ Sonar Readings and/or Charts ■ TACAN Readings ■ Technical Reference Books ■ Test Records ■ Tide Tables ■ Underwater Work Techniques ■ USN Diving Manual Reference List ■ USN Instructions ■ USN Ship Salvage Manual ■ Visual Bearings ■ Weather Reports

Figure 6-5. Planning Data Sources

used to locate the debris field, and an ROV can identify target items located by the side scan sonar. Once the object of the search has been found, the site should be marked, preferably with an acoustic transponder (pinger) and/or a buoy. 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 to improve the dive plan. This method saves diver effort for recovering items of interest.

6-4.4 **Data Required for All Diving Operations.** Data involving the following general categories shall be collected and analyzed for all diving operations:

- Surface conditions
- Underwater conditions
- Equipment and personnel resources
- Assistance in emergencies

6-4.4.1 **Surface Conditions.** Surface conditions in the operating area affect both the divers and the topside team members. Surface conditions are influenced by location, time of year, wind, waves, tides, current, cloud cover, temperature, visibility, and the presence of other ships. Completing the Environmental Assessment Worksheet (Figure 6-6) helps ensure that environmental factors are not overlooked during planning. For an extensive dive mission, a meteorological detachment may be requested from the local or regional meteorological support activity.

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 ____________
____
Curent:
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 6-6. Environmental Assessment Worksheet. The Environmental Assessment Worksheet indicates categories of data that might be gathered for an operation. Planners may develop an assessment methodology to suit the particular situation. The data collected is vital for effective operations planning, and is also of value when filing Post Salvage Reports.

6-4.4.1.1 ***Natural Factors.*** Normal conditions for the area of operations can be determined from published tide and current tables, sailing directions, notices to mariners, and special charts that show seasonal variations in temperature, wind, and ocean currents. Weather reports and long-range weather forecasts shall be studied to determine if conditions will be acceptable for diving. Weather reports shall be continually monitored while an operation is in progress.

NOTE **Diving shall be discontinued if sudden squalls, electrical storms, heavy seas, unusual tide or any other condition exists that, in the opinion of the Diving Supervisor, jeopardizes the safety of the divers or topside personnel.**

6-4.4.1.2 ***Sea State.*** A significant factor is the sea state (Figure 6-7). 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 shall be secured by at least a two-point moor. Exceptions to diving from a two-point moor may 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 cannot moor due to depth. A three- or four-point moor, while more difficult to set, may be preferred depending on dive site conditions.

Divers are not particularly affected by the action of surface waves unless operating in surf or shallow waters, or if the waves are exceptionally large. Surface waves may become a serious problem when the diver enters or leaves the water and during decompression stops near the surface.

6-4.4.1.3 ***Tender Safety.*** Effective dive planning shall 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 topside personnel may endanger the safety of a diver. Tending personnel shall guard against:

- Sunburn and windburn
- Hypothermia and frostbite
- Heat exhaustion

Sea State	Description	Wind Force (Beaufort)	Wind Descrip-tion	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	5-3	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	15-16	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	45-47	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 seriously affected.	12	Hurricane	64-71	>64	>80

Figure 6-7. Sea State Chart.

Actual Air Temp °F (°C)	Wind MPH							
	5	10	15	20	25	30	35	40
	Equivalent Chill Temperature °F (°C)							
40 (4)	35 (2)	30 (-1)	25 (-4)	20 (-7)	15 (-9)	10 (-12)	10 (-12)	10 (-12)
35 (2)	30 (-1)	20 (-7)	15 (-9)	10 (-12)	10 (-12)	5 (-15)	5 (-15)	0 (-17)
30 (-1)	25 (-4)	15 (-9)	10 (-12)	5 (-15)	0 (-17)	0 (-17)	0 (-17)	-5 (-21)
25 (-4)	20 (-7)	10 (-12)	0 (-17)	0 (-17)	-5 (-21)	-10 (-23)	-10 (-23)	-15 (-26)
20 (-7)	15 (-9)	5 (-15)	-5 (-21)	-10 (-23)	-15 (-26)	-20 (-29)	-20 (-29)	-20 (-29)
15 (-9)	10 (-12)	0 (-17)	-10 (-23)	-15 (-26)	-20 (-29)	-25 (-32)	-25 (-32)	-30 (-34)
10 (-12)	5 (-15)	-10 (-23)	-20 (-29)	-25 (-32)	-30 (-34)	-30 (-34)	-30 (-34)	-35 (-37)
5 (-15)	0 (-17)	-15 (-26)	-25 (-32)	-30 (-34)	-35 (-37)	-40 (-40)	-40 (-40)	-45 (-43)
0 (-17)	-5 (-15)	-20 (-24)	-30 (-34)	-35 (-37)	-45 (-43)	-55 (-46)	-50 (-46)	-55 (-48)
-5 (-21)	-10 (-23)	-25 (-32)	-40 (-40)	-45 (-43)	-50 (-46)	-65 (-54)	-60 (-51)	-60 (-51)
-10 (-23)	-15 (-26)	-35 (-37)	-45 (-43)	-50 (-46)	-60 (-54)	-70 (-57)	-65 (-54)	-70 (-57)
-15 (-26)	-20 (-29)	-40 (-40)	-50 (-46)	-60 (-51)	-65 (-54)	-70 (-57)	-75 (-60)	-75 (-60)
-20 (-29)	-25 (-32)	-45 (-43)	-60 (-51)	-65 (-54)	-75 (-60)	-80 (-62)	-85 (-65)	-90 (-68)
-25 (-32)	-30 (-34)	-50 (-46)	-65 (-45)	-75 (-60)	-80 (-62)	-85 (-65)	-90 (-68)	-95 (-71)
-30 (-34)	-35 (-37)	-60 (-51)	-70 (-57)	-80 (-62)	-90 (-68)	-95 (-71)	-100 (-73)	-100 (-73)
-35 (-37)	-40 (-40)	-65 (-54)	-80 (-62)	-85 (-65)	-95 (-71)	-100 (-73)	-105 (-76)	-110 (-79)
-40 (-40)	-45 (-43)	-70 (-57)	-85 (-65)	-95 (-71)	-105 (-76)	-110 (-79)	-115 (-82)	-115 (-82)
-45 (-43)	-50 (-46)	-75 (-60)	-90 (-68)	-100 (-73)	-110 (-79)	-115 (-82)	-120 (-85)	-125 (-87)
-50 (-46)	-55 (-48)	-80 (-62)	-100 (-73)	-110 (-79)	-120 (-85)	-125 (-87)	-130 (-90)	-130 (-90)
-55 (-48)	-60 (-51)	-90 (-68)	-105 (-76)	-115 (-82)	-125 (-87)	-130 (-90)	-135 (-93)	-140 (-96)
-60 (-51)	-70 (-57)	-95 (-71)	-110 (-79)	-120 (-85)	-135 (-93)	-140 (-96)	-145 (-98)	-150 (-101)

LITTLE DANGER

INCREASING DANGER (flesh may freeze within one minute)

GREAT DANGER (flesh may freeze within 20 seconds)

Figure 6-8. Equivalent Windchill Temperature Chart.

6-4.4.1.4 ***Windchill Factor.*** In cold, windy weather, the windchill factor shall 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 windchill factor is equivalent to 5°F (Figure 6-8). For information on ice and cold water diving operations, refer to Chapter 11.

6-4.4.1.5 ***Surface Visibility.*** 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 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.

6-4.4.2 **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 special support equipment such as underwater lights, cameras, ROV, etc.

Depth must be carefully measured and 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 shall be verified by either a lead-line sounding, a pneumofathometer (Figure 6-9), or a high resolution sonar (bottom finder or fish finder). Depth readings taken from a chart should only be used as an indication of probable depth.

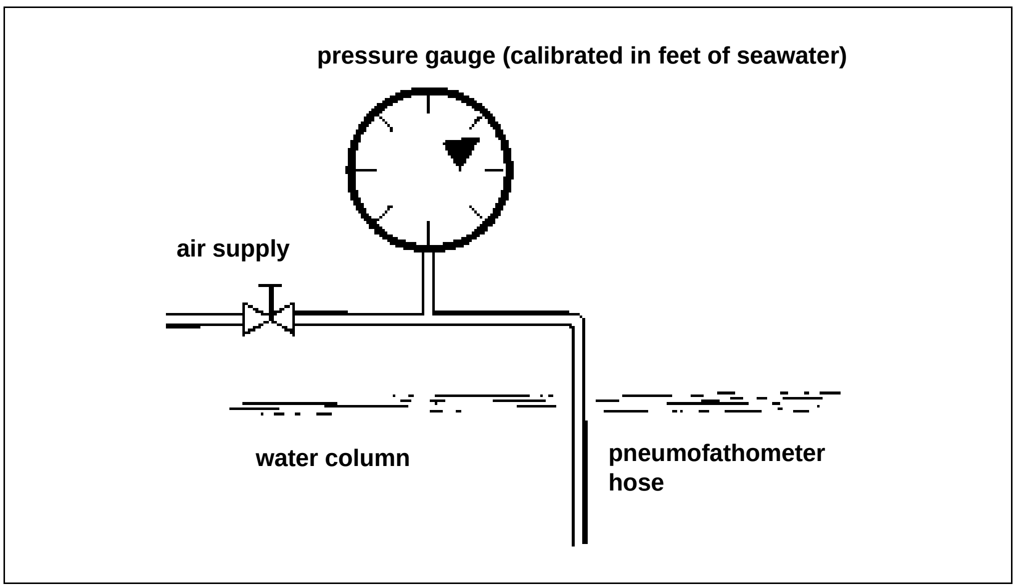


Figure 6-9. Pneumofathometer. The pneumofathometer hose is attached to a diver or weighted object and lowered to the depth to be measured. Water is forced out of the hose by pressurized air until a generally constant reading is noted on the pressure gauge. The air supply is secured, and the actual depth (equal to the height of the water column displaced by the air) is read on the gauge.

6-4.4.3 **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.

TYPE	CHARACTERISTICS	VISIBILITY	DIVER MOBILITY ON BOTTOM
Rock	Smooth or jagged, minimum sediment	Generally unrestricted by dive movement	Good, exercise care to prevent line snagging and falls from ledges
Coral	Solid, sharp and jagged, found in tropical waters only	Generally unrestricted by diver movement	Good, exercise care to prevent line snagging and falls from ledges
Gravel	Relatively smooth, 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 6-10. Bottom Conditions and Effects Chart.

Independent verification of the type of bottom should be obtained by sample or observation. Figure 6-10 outlines the basic types of bottoms and the characteristics of each.

6-4.4.4 **Tides and Currents.** The basic types of currents that affect diving operations are:

- **River or Major Ocean Currents**. 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, water depth, 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 than that observed on the surface.

- **Ebb Tides**. Current produced by the ebb and flow of the tides may add to or subtract from any existing current.

- **Undertow or Rip Current**. Undertow or rip currents are caused by the rush of water returning to the sea from waves breaking along a shoreline. 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 tables, can vary significantly from day to day in force and location.

- **Surface Current Generated by Wind**. 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 especially when planning surface swims and SCUBA dives.

6-4.4.4.1 ***Equipment Requirements for Working in Currents.*** A diver wearing a surface-supplied outfit, such as the MK 21 SSDS with heavy weights, can usually work in currents up to 1.5 knots without undue difficulty. A diver supplied with an additional weighted belt 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.

6-5 IDENTIFY OPERATIONAL HAZARDS

Underwater environmental conditions have a major influence on the selection of divers, diving technique, and the equipment to be used. In addition to environmental hazards, a diver may be exposed to operational hazards that are not unique to the diving environment. This section outlines the environmental and operational hazards that may impact an operation.

6-5.1 Underwater 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 fsw. Horizontal visibility is almost always less than vertical 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 can also affect visibility. 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.

6-5.2 Temperature. Figure 6-11 illustrates how water temperature can affect a diver's performance, and is intended as a planning guide. A diver's physical condition, amount of body fat, and thermal protection equipment determine how long exposure to extreme temperatures can be endured safely. In cold water, ability to concentrate and work efficiently will decrease rapidly. Even in water of moderate temperature (60–70°F, 15.5–21.5°C), the loss of body heat to the water can quickly bring on diver exhaustion.

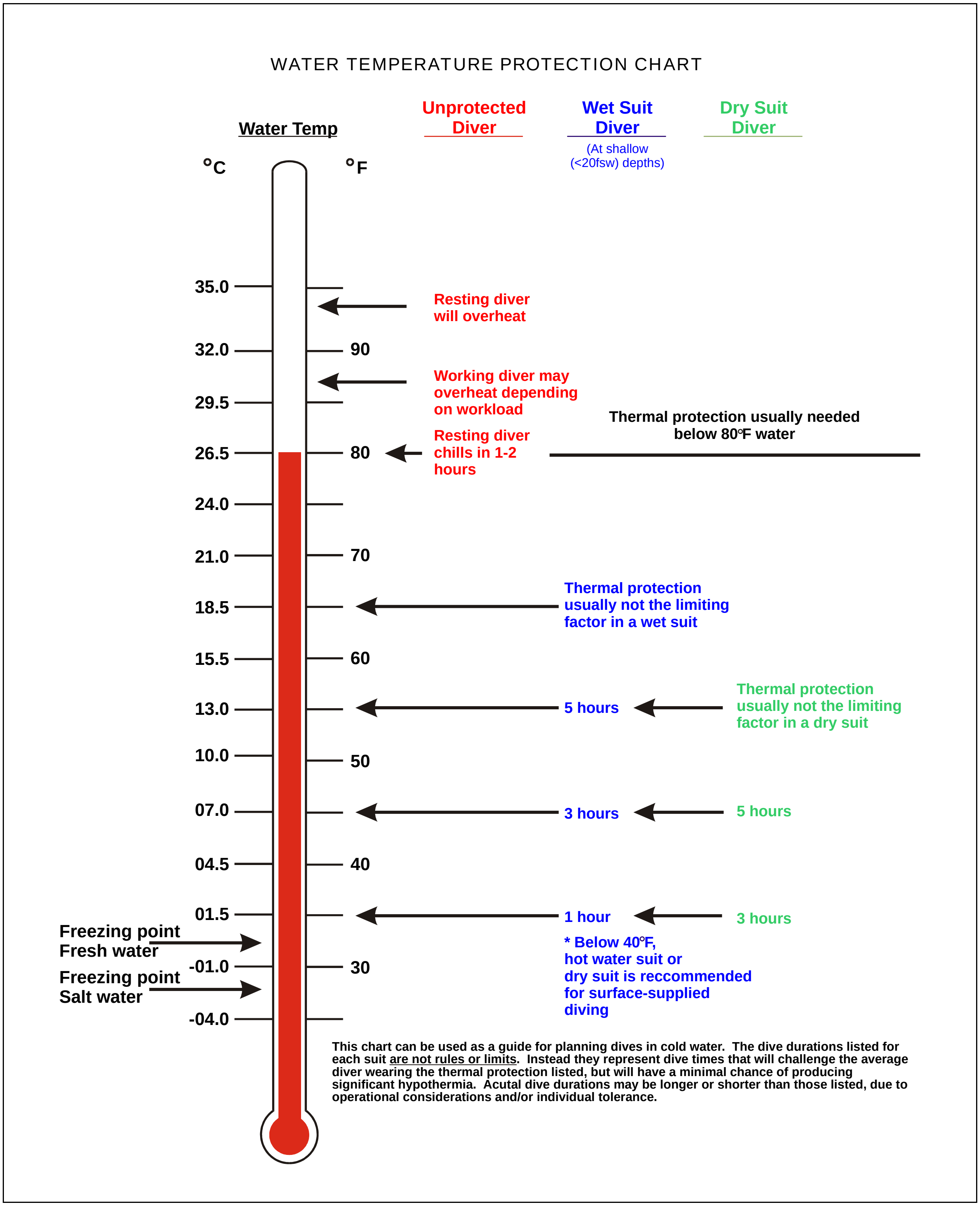


Figure 6-11. Water Temperature Protection Chart.

6-5.3 **Warm Water Diving.** Warm water diving is defined as those diving operations that occur in water temperatures exceeding 88° F. During recent studies at the Navy Experimental Diving Unit, physiological limits have been developed for diving operations in water temperatures up to 99°F. Diving in water temperatures above 99°F should not be attempted without first contacting NAVSEA 00C.

6-5.3.1 **Operational Guidelines and Safety Precautions.** These guidelines are based on data collected from heat acclimated divers dressed in UDT swim trunks and t-shirts who were well rested, calorically replete, well hydrated, and had no immediate heat exposure prior to starting exercise. Exercise rate for the divers replicated a moderate swimming effort. Conditions that contribute to thermal loading such as heavy work rates, significant pre/post dive activities, and various diver dress (dive skins/wetsuits/dry suits) can reduce exposure limits appreciably. Guidelines for exposure limits are based on diver dress and water temperatures. The following precautions apply to all warm water diving operations above 88°F:

- Weight losses up to 15 lbs (or 6-8% of body weight) due to fluid loss may occur and mental and physical performance can be affected. Divers should hydrate fully (approximately 500 ml or 17 oz) two hours before diving. Fluid loading in excess of the recommended 500 ml may cause life-threatening pulmonary edema and should not be attempted.

- Hydrating with water or a glucose/electrolyte beverage should occur as soon as possible after diving. Approximately 500 ml should be replaced for each hour of diving.

- Exposure limits represent maximum cumulative exposure over a 12 hour period. Divers should be hydrated and calorically replete to baseline weight, rested, and kept in a cool environment for at least 12 hours before a repeat exposure to warm water is deemed safe.

NOTE **The following are the general guidelines for warm water diving. Specific UBAs may have restrictions greater than the ones listed below; refer to the appropriate UBA Operations and Maintenance manual. The maximum warm water dive time exposure limit shall be the lesser of the approved UBA operational limits, canister duration limits, oxygen bottle duration or the diver physiological exposure limit.**

- A diver working at a moderate rate e.g. swimming at 0.8 kts or less:

  88°-94°F - limited to canister/O_2 bottle duration or diver aerobic endurance

  94°-97°F - limited to three hours based on physiological limits.

  97°-99°F - limited to one hour based on physiological limits.

NOTE **In cases of SDV and DDS operations, thermal loading may change during the course of the mission. Exposure times should be reduced and fluids replaced during the dive when possible.**

- A resting diver e.g. during decompression:
  88°-94°F - limited to canister duration.
  94°-97°F - limited to canister duration.
  97°-99°F - limited to two hours based on physiological limits.

6-5.3.2 **Mission Planning Factors.** The following mission planning factors may mitigate thermal loading and allow greatest utilization of the exposure limits:

1. Conduct diving operations at night, dusk, or dawn to reduce heat stress incurred from sun exposure and high air temperatures.

2. Avoid wearing a hood with a dive skin to allow evaporative cooling.

3. When possible avoid wearing dive skin or anti-chafing dress. Although the effect of various diver dress is not known, it is expected that safe exposure durations at temperatures above 96°F will be less.

4. Follow the guidelines in paragraph 3-10.4 regarding acclimatization. Reduce the intensity of the diving for five days immediately prior to the diving operation.

5. Ensure divers maintain physical conditioning during periods of warm water diving.

6. Methods of cooling the diver should be employed whenever possible. These include using hot water suits to supply cold water to the diver and the use of ice vests.

Mission planning should also include recognition and management of heat stress injuries as part of pre-dive training and briefing. The diver and topside personnel shall be particularly alert for the symptoms of heat stress. Further guidance is contained in paragraph 3-10.4.4 (Excessive Heat - Hyperthermia), paragraph 3-12.1 (Dehydration), and Figure 3-6 (Oxygen Consumption and RMV at Different Work Rates).

6-5.4 **Contaminated Water.** When planning for contaminated water diving, medical personnel should be consulted to ensure proper pre-dive precautions are taken and post-dive monitoring of divers is conducted. In planning for operations in polluted waters, protective clothing and appropriate preventative medical procedures shall be taken. Diving equipment shall be selected that gives the diver maximum protection consistent with the threat. Resources outside the scope of this manual may be required to deal with nuclear, biological, or chemical contaminants. Resources and technical advice for dealing with contaminated water diving conditions are available in the *Guidance for Diving in Contaminated Waters*, SS521-AJ-PRO-010, or contact NAVSEA 00C3.

6-5.5 Chemical Contamination. Oil leaking from underwater wellheads or damaged tanks can foul 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. Diving units should not conduct the dive until the contaminant has been identified, the safety factors evaluated, and a process for decontamination set up. Divers operating in waters where a chemical or chemical warfare threat is known or suspected shall evaluate the threat and protect themselves as appropriate. The MK 21 UBA with a double exhaust and a dry suit dress assembly affords limited protection for diving in polluted and contaminated water. Refer to the *MK 21 UBA NAVSEA Technical Manual*, S6560-AG-OMP-010, for more information on using the MK 21 UBA with a dry suit assembly.

6-5.6 Biological Contamination. A diver working near sewer outlets may be exposed to biological hazards. 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. External ear prophylaxis should be provided to diving personnel to prevent ear infections.

6-5.7 Altitude Diving. Divers may be required to dive in bodies of water at higher altitudes. Planning shall address the effects of the atmospheric pressures that may be much lower than those at sea level. U.S. Navy Air Decompression Tables are authorized for use at altitudes up to 300 feet above sea level without corrections (see paragraph 9-12). Transporting 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 shall be alert for symptoms of hypoxia and decompression sickness after the dive due to the lower oxygen partial pressure and atmospheric pressure.

6-5.8 Underwater Obstacles. Various underwater obstacles, such as wrecks or discarded munitions, offer serious hazards to diving. Wrecks and dumping grounds are often noted on charts, but the actual presence of obstacles might not be discovered until an operation begins. This is a good reason for scheduling a preliminary inspection dive before a final work schedule and detailed dive plan is prepared.

6-5.9 Electrical Shock Hazards. Electrical shock may occur when using electric welding or power equipment. All electrical equipment shall be in good repair and be inspected before diving. Although equipped with test buttons, electrical Grounds Fault Interrupters (GFI) often do not provide any indication when the unit has experienced an internal component failure in the fault circuitry. Therefore, GFI component failure during operation (subsequent to testing the unit) may go unnoticed. Although this failure alone will not put the diver at risk, the GFI will not protect the diver if he is placed in contact with a sufficiently high fault current. The following is some general information concerning GFIs:

- GFIs are required when line voltage is above 7.5 VAC or 30 VDC.

- GFIs shall be capable of tripping within 20 milliseconds (ms) after detecting a maximum leakage current of 30 milliamps (ma).

- GFIs require an established reference ground in order to function properly. Cascading GFIs could result in loss of reference ground; therefore, GFIs or equipment containing built-in GFIs should not be plugged into an existing GFI circuit.

In general, three independent actions must occur simultaneously to electrically shock a diver:

- The GFI must fail.

- The electrical equipment which the diver is operating must experience a ground fault.

- The diver must place himself in the path between the fault and earth ground.

6-5.9.1 **Reducing Electrical Shock Hazards.** The only effective means of reducing electrical shock hazards are to ensure:

- Electrical equipment is properly maintained.

- All electrical devices and umbilicals are inspected carefully before all operations.

- Electrical umbilicals are adequately protected to reduce the risk of being abraded or cut when pulled over rough or sharp objects.

- Personnel are offered additional protection through the use of rubber suits (wet, dry, or hot-water) and rubber gloves.

- GFI circuits are tested at regular intervals throughout the operation using built-in test circuits.

Divers operating with remotely operated vehicles (ROVs) should take similar precautions to ensure the ROV electrical system offers the required protection. Many new ROVs use extremely high voltages which make these protective actions even more critical to diver safety.

NEDU has been tasked with repair and testing of the Daniel Woodhead company Model 1670 and 1680 GFIs. Woodhead GFIs needing repair or testing should be sent to:

Navy Experimental Diving Unit
Shipping and Receiving Officer
321 Bullfinch Road
Panama City, FL 32407-7015
ATTN: Code 03D1

Units should be sent to the above address with a DD-1149 and complete return address and written details of problem.

6-5.9.2 **Securing Electrical Equipment.** The Ship Repair Safety Checklist for Diving requires underwater electrical equipment to be secured while divers are working over the side. While divers are in the water:

- Ship impressed current cathodic protection (ICCP) systems must be secured, tagged out, and confirmed secured before divers may work on an ICCP device such as an anode, dielectric shield, or reference cell.
- When divers are required to work close to an active ICCP anode and there is a risk of contact with the anode, the system must also be secured.
- In situations other than those described above, the ICCP is to remain active.
- Divers working within 15 feet of active systems must wear a full dry suit, unisuit, or wet suit with hood and gloves.
- All other underwater electrical equipment shall be secured while divers are working over the side.

6-5.10 **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 outlined in SWO 60-AA-MMA-010 shall be followed. Divers should stay clear of old or damaged munitions. Divers should get out of the water when an explosion is imminent.

WARNING **Welding or cutting torches may cause an explosion on penetration of gas-filled compartments, resulting in serious injury or death.**

6-5.11 **Sonar.** Appendix 1A provides guidance regarding safe diving distances and exposure times for divers operating in the vicinity of ships transmitting with sonar.

6-5.12 **Nuclear Radiation.** Radiation may be encountered as the result of an accident, proximity to weapons or propulsion systems, weapons testing, or occasionally natural conditions. Radiation exposure can cause serious injury and illness. Safe tolerance levels have been set and shall not be exceeded. These levels may be found in the *Radiological Control Manual*, NAVSEA 0389-LP-660-6542. Local instructions may be more stringent and in such case shall be followed. Prior to diving, all dive team members shall be thoroughly knowledgeable of the local/command radiological control requirements. When required divers shall have a Thermal Luminescence Dosimeter (TLD) or similar device and be apprised of the locations of items such as the reactor compartment, discharges, etc.

6-5.13 **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, while some are merely an uncomfortable annoyance. Most dangers from marine life are largely overrated because most underwater animals leave man alone. All divers should be able to identify the dangerous species that are likely to be found in the area of operation and should know how to deal with each. Refer to

Appendix 5C for specific information about dangerous marine life, including identification factors, dangerous characteristics, injury prevention, and treatment methods.

6-5.14 **Vessels and Small Boat Traffic.** 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 shall be properly notified by International Code signal flags (Figure 6-12). 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 diving signals and take the precautions required to ensure that these vessels remain clear of the diving area. Hazards associated with vessel traffic are intensified under conditions of reduced visibility.

NOTE **When small civilian boats are in the area, use the civilian Sport Diver flag (red with white diagonal stripe) as well as "Code Alpha."**

6-5.15 **Territorial Waters.** Diving operations conducted in the territorial waters of other nations shall be properly coordinated prior to diving. Diving units must be alert to the presence of foreign intelligence-collection ships and the potential for hostile action when diving in disputed territorial waters or combat zones.

6-6 SELECT DIVING TECHNIQUE

The four main types of air diving equipment used in U.S. Navy diving operations are (Figure 6-13):

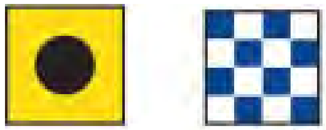
1. Open-circuit SCUBA
2. MK 20 MOD 0 surface-supplied gear
3. MK 21 MOD 1 surface-supplied gear
4. EXO BR MS Full Face Mask surface-supplied or open-circuit SCUBA

6-6.1 **Factors to Consider when Selecting the Diving Technique.** When selecting the technique to be used for a dive, the following factors must be considered:

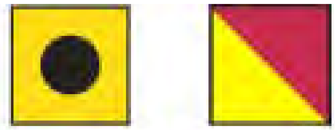
- Duration and depth of the dive
- Type of work to be performed
- Environmental conditions
- Time constraints

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 and shall not be exceeded without specific approval of the Chief of Naval Operations in accordance with the OPNAVINST 3150.27 series (see Figure 6-14).

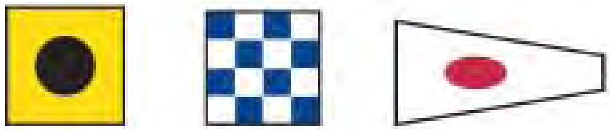
The increase of air consumption with depth limits open-circuit SCUBA to 130 fsw for reasonable working dives. The hazards of nitrogen narcosis and decompression



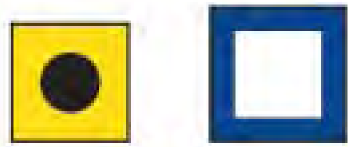
IN: “I require a diver.”



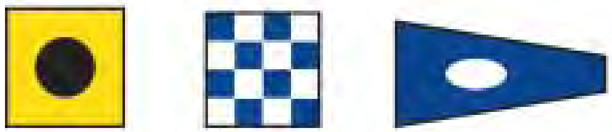
IO: “I have no diver.”



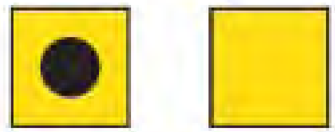
IN1: “I require a diver to clear my propeller.”



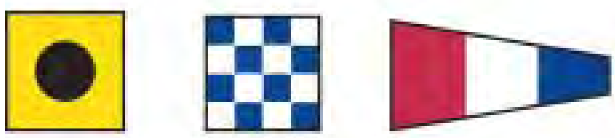
IP: “A diver will be sent as soon as possible or at time indicated.”



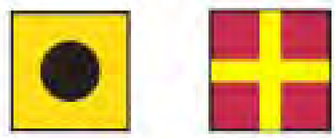
IN2: “I require a diver to examine bottom.”



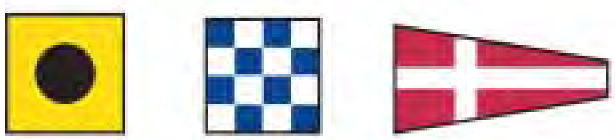
IQ: “Diver has been attacked by diver’s disease and requires decompression chamber treatment.”



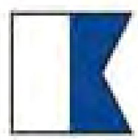
IN3: “I require a diver to place collision mat.”



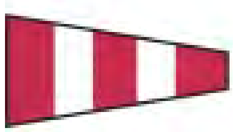
IR: “I am engaged in submarine survey work (underwater operations). Keep clear of me and go slow.”



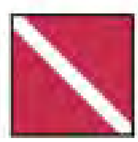
IN4: “I require a diver to clear my anchor.”



A: “I have a diver down; Keep well clear at slow speed.”



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.)

Figure 6-12. International Code Signal Flags.

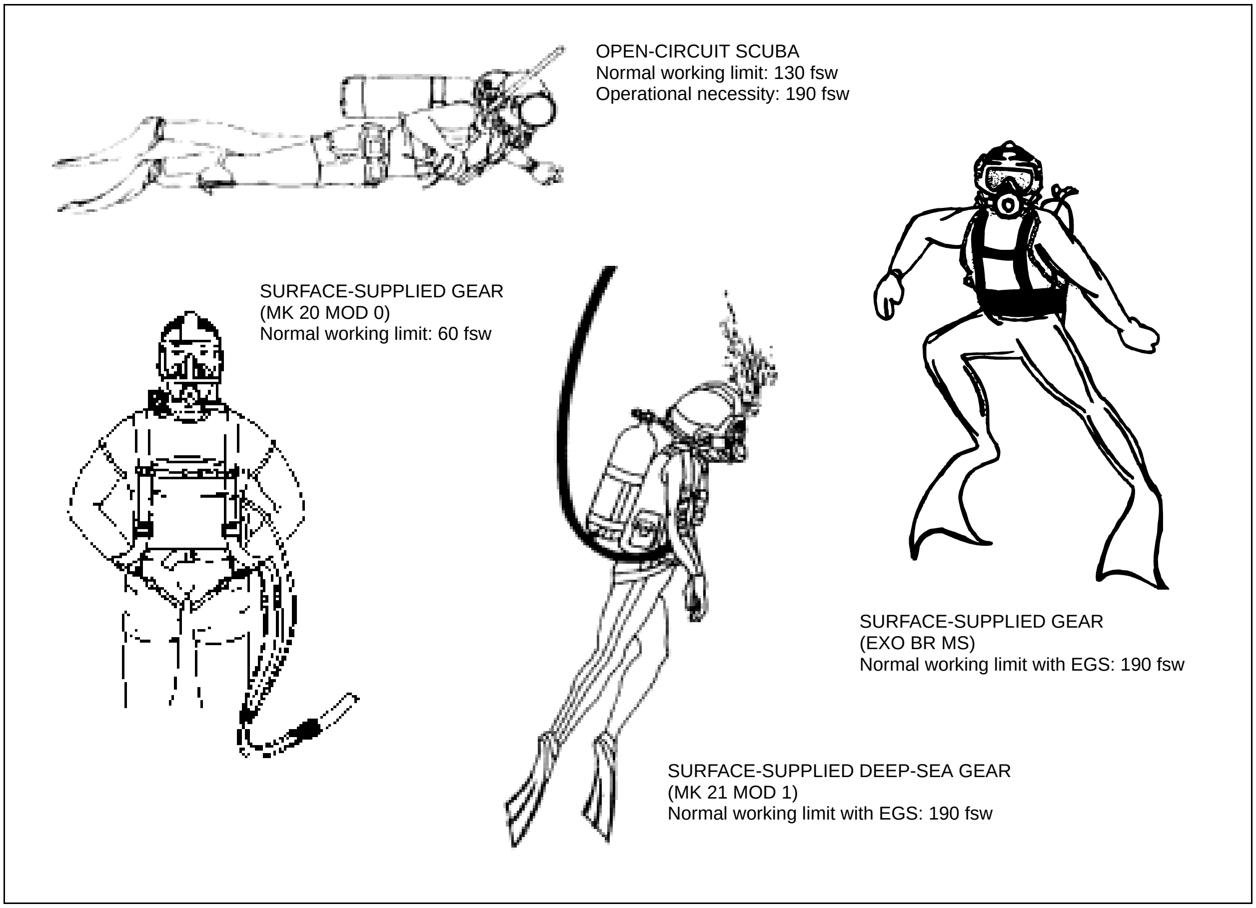


Figure 6-13. Air Diving Techniques. A choice of three air diving techniques are available: open circuit SCUBA, surface-supplied gear (MK 20 MOD 0), surface-supplied deep-sea gear (MK 21 MOD 1), and surface-supplied deep sea gear (EXO BR MS).

further limit open-circuit SCUBA to 190 fsw even for short duration dives. Surface-supplied equipment is generally preferred between 130 and 190 fsw, although open-circuit SCUBA may be used under some circumstances. Decompression SCUBA dives and SCUBA dives deeper than 130 fsw may be conducted when dictated by operational necessity and with the specific approval of the Commanding Officer or the Officer-in-Charge. All open-circuit SCUBA dives beyond 100 fsw shall employ cylinders having a capacity of at least 100 cubic feet.

In some operations there may be no clear-cut choice of which diving technique to use. Selecting a diving technique may depend upon availability of equipment or trained personnel. The following comparison of SCUBA and surface-supplied techniques highlights the significant differences between the methods and outlines the effect these differences will have on planning.

6-6.2 Breathhold Diving Restrictions. Breathhold diving shall be confined to tactical and work situations that cannot be effectively accomplished by the use of underwater breathing apparatus and applicable diver training situations such as SCUBA pool phase and shallow water obstacle/ordnance clearance. Breathhold diving includes the practice of taking two or three deep breaths prior to the dive. The

NORMAL AND MAXIMUM LIMITS FOR AIR DIVING		
Depth fsw (meters)	**Limit for Equipment**	**Notes**
60 (18)	MK 21 MOD 1 diving equipment, maximum working limit without Emergency Gas Supply (EGS)	a
60 (18)	MK 20 MOD 0 equipment surface-supplied	a
60 (18)	Maximum depth for standby SCUBA diver using a single cylinder with less than 100 SCF capacity	
100 (30)	Open-circuit SCUBA with less than 100 SCF cylinder capacity	b
130 (40)	Open-circuit SCUBA, normal working limit	b
190 (58)	Open-circuit SCUBA, maximum working limit with Commanding Officer's or Officer-in-Charge's permission	b, d
190 (58)	MK 21 MOD 1 and EXO BR MS (air) diving equipment with EGS, normal working limit	c, d, e
285 (87)	MK 21 MOD 1 and EXO BR MS (air) diving equipment with EGS, maximum working limit, exceptional exposure with authorization from the Chief of Naval Operations (N773)	c, d, e

General Operating Notes (Apply to all):

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 (N773).
2. Do not exceed the limits for exceptional exposures for the Standard Air Decompression Table.
3. In an emergency, any operable recompression chamber may be used for treatment if deemed safe to use by the Diving Supervisor.

Specific Notes:

a. When diving in an enclosed space, EGS must be used by each diver.

b. Under normal circumstances, do not exceed the limits of the No-Decompression Table. Dives requiring decompression may be made if considered necessary with approval by the Commanding Officer or Officer-in-Charge of the diving command. The total time of a SCUBA dive (including decompression) shall not exceed the duration of the apparatus in use, disregarding any reserves.

c. A Diving Medical Officer is required at the site for all air dives deeper than 190 fsw and for exceptional exposure dives.

d. All planned air decompression dives deeper than 130 fsw require a certified recompression chamber on site. **An on-site chamber is defined as a certified and ready chamber accessible within 30 minutes of the dive site by available transportation.**

e. The Exceptional Exposure Tables, printed in red in the Standard Air Tables, have a significantly higher probability of DCS and CNS oxygen toxicity.

Figure 6-14. Normal and Maximum Limits for Air Diving.

diver shall terminate the dive and surface at the first sign of the urge to breath. Hyperventilation (excessive rate and depth of breathing prior to a dive, as differentiated from two or three deep breaths prior to a dive) shall not be practiced because of the high possibility of causing unconsciousness under water.

6-6.3 Operational Characteristics of SCUBA. The term *SCUBA* refers to open-circuit air SCUBA unless otherwise noted. 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.

6-6.3.1 **Mobility.** 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 shall be able to ascend directly to the surface in case of emergency.

WARNING SCUBA equipment is not authorized for use in enclosed space diving.

6-6.3.2 **Buoyancy.** SCUBA equipment is designed to have nearly neutral buoyancy when in use, permitting the diver to change or maintain depth with ease. This allows the SCUBA diver to work at any level in the water column.

6-6.3.3 **Portability.** 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.

6-6.3.4 **Operational Limitations.** Divers shall adhere to the operational limitations contained in Figure 6-14. Bottom time is limited by the SCUBA's fixed air supply, which is depleted more rapidly when diving deep or working hard.

6-6.3.5 **Environmental Protection.** 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.

6-6.4 Operational Characteristics of SSDS. Surface-supplied diving systems can be divided into two major categories: lightweight full face mask (MK 20), and deep-sea (MK 21) gear.

6-6.4.1 **Mobility.** Surface-supplied gear allows the diver almost as much mobility as SCUBA. The primary use for deep-sea gear is bottom work in depths up to 190 fsw.

6-6.4.2 **Buoyancy.** The buoyancy associated with SSDS varies with the diving dress selected. Variable Volume Dry Suit (VVDS) provides the greatest buoyancy control (see paragraph 7-3.1.2), making it a desirable technique for working on muddy bottoms, conducting jetting or tunneling, or working where the reaction forces of tools are high.

6-6.4.3 **Operational Limitations.** Divers using surface supplied gear are restricted to the operational limitations described in Figure 6-14. Additional limitations of using surface-supplied gear include additional topside support personnel and lengthy predive and postdive procedures.

6-6.4.4 **Environmental Protection.** Surface-supplied diving systems can offer the diver increased thermal protection when used with a Hot Water or VVDS. The MK 21 helmet can increase protection of the diver's head. Because the diver's negative buoyancy is easily controlled, an SSDS allows diving in areas with strong currents.

6-7 SELECT EQUIPMENT AND SUPPLIES

6-7.1 **Equipment Authorized for Navy Use.** Equipment procured for use in the U.S. Navy has been tested under laboratory and field conditions to ensure that it will perform according to design specifications. A vast array of equipment and tools is available for use in diving operations. The NAVSEA/00C Diving Equipment Authorized for U.S. Navy Use (ANU) list identifies much of this equipment and categorizes diving equipment authorized for U.S. Navy use.

6-7.2 **Air Supply.** The quality of diver's breathing air is vitally important. Air supplies provided to the diver in tanks or through a compressor shall meet five basic criteria.

1. Air shall conform to standards for diving air purity found in paragraph 4-3 and paragraph 4-4.

2. Flow to the diver must be sufficient. Refer to the appropriate equipment operations and maintenance manual for flow requirements.

3. Adequate overbottom pressure shall be maintained at the dive station.

4. Adequate air supply shall be available to support the duration and depth of the dive (see paragraph 7-4.1 for SCUBA; paragraph 8-2.2 for MK 21).

5. A secondary air supply shall be available for surface-supplied diving.

6-7.3 **Diving Craft and Platforms.** Regardless of the technique being supported, craft used for diving operations shall:

- 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

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 additional equipment should be anticipated as far in advance as possible.

6-7.4 Deep-Sea Salvage/Rescue Diving Platforms.

- **Auxiliary Rescue/Salvage Ship (ARS) (Safeguard Class).** The mission of the ARS ship is to assist disabled ships, debeach stranded vessels, fight fires alongside other ships, lift heavy objects, recover submerged objects, tow other vessels, and perform manned diving operations. The ARS class ships carry a complement 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 Tender (AS)**. U.S. submarine tenders are designed specifically for servicing nuclear-powered submarines. Submarine tenders are fitted with a recompression chamber used for hyperbaric treatments. Submarine tenders support underwater ship husbandry and maintenance and security swims.

- **Fleet Ocean Tug (T-ATF)**. T-ATFs are operated by the Military Sealift Command. Civilian crews are augmented with military communications and diving detachments. In addition to towing, these large ocean-going tugs serve as salvage and diving platforms.

- **Diving Tender (YDT)**. These vessels are used to support shallow-water diving operations. Additionally, a wide variety of Standard Navy Dive Boats (SNDB), LCM-8, LCM-6, 50-foot work boats, and other yard craft have been fitted with surface-supplied dive systems.

6-7.5 **Small Craft.** SCUBA operations are normally conducted from small craft. 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.

6-8 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 diving team may include the Diving Officer, Master Diver, Diving Supervisor, Diving Medical Officer, divers qualified in various techniques and equipment, support personnel (tenders—qualified divers if possible), recorder, and medical personnel, as indicated by the type of operation (Figure 6-15). Other members of the ship's company, when properly instructed, provide support in varying degrees in such roles as boat crew, winch operators, and line handlers.

Figure 6-15. MK 21 Dive Requiring Two Divers. The team consists of one Diving Supervisor, two divers, a standby diver, one tender per diver, comms and logs, console operator, and extra personnel (as required).

6-8.1 **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. The minimum number of personnel required on station for each particular type of diving equipment is provided in Figure 6-16. Minimum levels as determined by ORM shall be maintained; levels must be increased as necessary to meet anticipated operational conditions and situations.

6-8.2 **Commanding Officer.** The ultimate responsibility for the safe and successful conduct of all diving operations rests with the Commanding Officer. The Commanding Officer's responsibilities for diving operations are defined and the provisions of U.S. Navy Regulations and other fleet, force, or command regulations confirm specific authority. 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.

6-8.3 **Command Diving Officer.** The Command Diving Officer's primary responsibility is the safe conduct of all diving operations within the command. The Command Diving Officer will become thoroughly familiar with all command diving techniques and have a detailed knowledge of all applicable regulations and is responsible for all operational and administrative duties associated with the

MINIMUM MANNING LEVELS FOR AIR DIVING

	Open circuit SCUBA Operations		Surface-Supplied Operations
	Single Diver	Buddy Pair	
Diving Supervisor	1	1	1
Comms and Logs	(a)	(a)	(a)
Console Operator			(a)
Diver	1	2	1
Standby Diver	1	1	1
Diver Tender (b, c)	1(b)		1(b)
Standby Diver Tender	(c)	(c)	1
Total	4(d)	4	5(e)

WARNING
These are the minimum personnel levels required. ORM may require these personnel levels be increased so the diving operations can be conducted safely. See Paragraph 6-1.1 and 6-9.1

NOTES:

(a) Diving Supervisor may perform/assign Comms/Logs or Console Operator positions as necessary or required by the system/operations/mission.

(b) See paragraph 6-8.8.5.2 for Tender Qualifications.

(c) If the standby diver is deployed, the Diving Supervisor shall tend the standby diver.

(d) The diver will be tended or have a witness float attached, see paragraph 7-3.1.7. A tender is required when the diver does not have free access to the surface, see paragraph 7-8.2 for further guidance. During mission essential open circuit SCUBA operations, minimum-manning level may be reduced to three qualified divers at the diving supervisors descretion.

(e) Although five is the minimum number of personnel for the MK III and Extreme Lightweight Dive System (XLDS) operations, six or more is highly recommended based on mission requirements and ORM.

Figure 6-16. Minimum Personnel Levels for Air Diving Stations.

command diving program. The Command Diving Officer is designated in writing by the Commanding Officer and must be a qualified diver. In the absence of a commissioned officer or a Master Diver, a senior enlisted diving supervisor may be assigned as the Command Diving Officer. On submarines the senior qualified diver may be assigned Command Diving Officer.

6-8.4 **Watchstation Diving Officer.** Personnel assigned as the Watchstation Diving Officer must be a qualified diver and is responsible to the Commanding Officer for the safe and successful conduct of the diving operation. The Watchstation Diving Officer provides overall supervision of diving operations, ensuring strict adherence to procedures and precautions. A qualified Diving Officer or Master Diver may be assigned this watchstation. The Watchstation Diving Officer must be designated in writing by the Commanding Officer.

Figure 6-17. Master Diver Supervising Recompression Treatment.

6-8.5 Master Diver.

6-8.5.1 **Master Diver Responsibilities.** 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 (Figure 6-17). He is directly responsible to the Commanding Officer, via the Diving Officer, for the safe conduct of all phases of diving operations. The Master Diver manages preventive and corrective maintenance on diving equipment, support systems, salvage machinery, handling systems, and submarine rescue equipment. The Master Diver, who also ensures that divers are trained in emergency procedures, conducts training and re-qualification of divers attached to the command. 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 oversees the efforts of the Diving Supervisor and provides advice and technical expertise. If circumstances warrant, the Master Diver shall relieve the Diving Supervisor and assume control of the dive station. In the absence of a Diving Officer, the Master Diver can assume the duties and responsibilities of the Diving Officer.

6-8.5.2 **Master Diver Qualifications.** The Master Diver has completed Master Diver evaluation course (CIN A-433-0019) successfully and is proficient in the operation of Navy-approved underwater breathing equipment, support systems, and recompression chambers. He is also trained in diagnosing and treating diving injuries and illnesses. The Master Diver is thoroughly familiar with operating 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 shall possess a comprehensive knowledge of the scope and application of all Naval instructions and publications pertaining to diving, and shall ensure that logs and reports are maintained and submitted as required.

6-8.6 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. Diving operations shall not be conducted without the presence of the Diving Supervisor. The diving supervisor has the authority and responsibility to discontinue diving operations in the event of unsafe diving conditions.

6-8.6.1 **Pre-dive Responsibilities.** The Diving Supervisor shall be included in preparing the operational plans. The Diving Supervisor shall consider 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 shall evaluate the qualifications and physical fitness of the divers selected for each particular job. The Diving Supervisor inspects all equipment and conducts pre-dive briefings of personnel.

6-8.6.2 **Responsibilities While Operation is Underway.** 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.

6-8.6.3 **Post-dive Responsibilities.** When the mission has been completed, the Diving Supervisor gathers appropriate data, analyzes the results of the mission, prepares reports to be submitted to higher authority, and ensures that required records are completed. These records may range from equipment logs to individual diving records.

6-8.6.4 **Diving Supervisor Qualifications.** The Diving Supervisor may be commissioned or enlisted depending on the size of the operation and the availability of qualified personnel. When qualifying a Diving Supervisor, selection is based on knowledge of diving technique, experience, level of training, and the competence of the available personnel. Regardless of rank, the Diving Supervisor shall be a qualified diver of demonstrated ability and experience. The Diving Supervisor shall be designated in writing by the Commanding Officer. Diving Supervisors under instruction shall stand their watches under the supervision of a qualified Diving Supervisor.

6-8.7 Diving Medical Officer. The Diving Medical Officer defines the proper course of medical action during medical emergencies. 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. The Diving

Medical Officer may modify recompression treatment tables, with the specific concurrence of the Commanding Officer. A Diving Medical Officer is required on site for all air dives deeper than 190 fsw, or for planned exceptional exposure air dives.

6-8.8 Diving Personnel.

6-8.8.1 **Diving Personnel Responsibilities.** While working, the diver shall keep topside personnel informed of conditions on the bottom, progress of the task, and of any developing problems that 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 shall 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 shall ensure that it is complete and in good repair.

6-8.8.2 **Diving Personnel Qualifications.**

Military divers shall be qualified and designated in accordance with instructions issued by the Naval Personnel Command (NPC) or as appropriate by USMC, U.S. Army, or U.S. Air Force orders. Civilian divers diving under military cognizance must be qualified in accordance with OPNAVINST 3150.27 (Series). The diver selected for an operation shall be qualified for the diving technique used, the equipment involved, and for diving to the depth required. Diving personnel assigned to the Navy Experimental Diving Unit (NEDU) and Naval Submarine Medical Research Laboratory (NSMRL) are exempt from such requirements as they are assigned as experimental diving test subjects and may be employed in experimental dive profiles as required within approved test protocols.

Figure 6-18. Standby Diver.

6-8.8.3 **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 shall have equivalent depth and operational capabilities. SCUBA shall not be used for the standby diver for surface-supplied diving operations.

6-8.8.3.1 ***Standby Diver Qualifications.*** 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 shall be dressed to the following points, MK 20 or MK 21 MOD 1, with strain relief connected 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 the mask and fins and have them ready to don immediately for quick deployment. For safety reasons at the discretion of the Diving Supervisor, the standby diver may remove the tank. 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 SCUBA standby diver shall be equipped with an octopus rig.

6-8.8.3.2 ***Deploying the Standby Diver as a Worker Diver.*** The Standby diver may be deployed as a working diver provided all of the following conditions are met:

1. Surface-supplied no-decompression dive of 60 fsw or less.

2. Same job/location, e.g., working on port and starboard propellers on the vessel:

   - Prior to deploying the standby diver, the work area shall 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 deploy as a working diver, but both divers shall be tended by a third diver who is outside the confined space.

NOTE The standby diver shall remain on deck ready for deployment when salvage operations diving is being done.

6-8.8.4 **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 shall watch out for the safety and well-being of his buddy and shall be alert for symptoms of nitrogen narcosis, decompression sickness, and carbon dioxide build up. A diver shall keep his buddy within sight and not leave his buddy alone except to obtain additional assistance in an emergency. If visibility is limited, a buddy line shall be used to maintain contact and communication. If SCUBA divers get separated and cannot locate each other, both divers shall surface immediately.

6-8.8.5 **Diver Tender.**

6-8.8.5.1 ***Diver Tender Responsibilities.*** The tender is the surface member of the diving team who works 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 (certain UWSH tasking may preclude this requirement, e.g., working in submarine ballast tanks, shaft lamination, dry habitat welding, etc.). The tender exchanges line-pull signals with the diver, keeps the Diving Supervisor informed of the line-pull signals and amount of diving hose/tending line over the side and remains alert for any signs of an emergency.

6-8.8.5.2 ***Diver Tender Qualifications.*** The tender should be a qualified diver. When circumstances require the use of a non-diver as a tender, the Diving Supervisor shall ensure that the tender has been thoroughly instructed in the required duties. If a substitute tender shall be employed during an operation, the Diving Supervisor must make certain that the substitute is adequately briefed before assuming duties.

6-8.8.6 **Recorder.** The recorder shall be a qualified diver. The recorder 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. In SCUBA operations, the Diving Supervisor may assume the duties of the recorder. The recorder is required to have on hand a copy of the U.S. Navy Standard Decompression Tables being used. 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 decompression requirements of the divers.

6-8.8.7 **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.

There are no hard and fast rules for deciding when a medication would preclude a diver from diving. In general, topical medications, antibiotics, birth control medication, and decongestants that do not cause drowsiness would not restrict diving. Diving Medical Personnel should be consulted to determine if any other drugs would preclude diving.

6-8.8.8 **Other Support Personnel.** Other support personnel may include almost any member of the command when assigned to duties that support diving operations. Some personnel need specific indoctrination. Small-Boat operators shall understand general 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 Figure 6-20 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 shall 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 shall be alert for any shifting of the moor or changing weather/sea conditions. He shall inform the Diving Officer and/or Diving Supervisor of any changes in these conditions.

6-8.8.9 **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.

6-8.8.10 **Physical Condition.** Diving candidates shall meet the specific physical requirements for divers set forth by the Commander Naval Medical Command and pass a physical screening test as outlined in MILPERSMAN Article 1220.100. Once qualified, the diver is responsible for maintaining good health and top physical condition.

Reference NAVMEDCOMINST 6200.15 (series) to provide guidance on suspension of diving duty of pregnant servicewomen.

Medical personnel assigned to a diving unit shall evaluate the day-to-day condition of each diver and the Diving Supervisor shall 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.

6-8.8.11 **Underwater Salvage or Construction Demolition Personnel.** Underwater salvage demolition personnel are trained in underwater precision explosives techniques and hold Navy Enlisted Classification (NEC) 5375. Salvage/Construction Demolition Diver personnel shall be currently certified and designated in accordance with the requirements specified in the OPNAVINST 8023.2 (series).

6-8.8.12 **Blasting Plan.** The senior Salvage/Construction Demolition Diver NEC 5375 via the MDV and Diving Officer is responsible for providing the Commanding Officer with a comprehensive and written blasting plan. At a minimum, the blasting plan contains:

- Demolition team organization
- Work description with alternatives
- Range standard operating procedures
- Prefiring procedures
- Postfiring procedures
- Area security plan

- 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 shall ensure the operation is not allowed to proceed until receiving specific approval from the Diving Supervisor and shall take charge of all misfires, ensuring they are handled in accordance with the approved plan.

6-8.8.13 **Explosive Handlers.** All divers who handle explosives shall be trained and certified in accordance with the OPNAVINST 8023.2 (series).

6-8.9 OSHA REQUIREMENTS FOR U.S. NAVY CIVILIAN DIVING

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 Safety and Health Administration (OSHA) diving standards, delineated in 29 CFR Part 1910 Subpart T; Subj: Commercial Diving Operations. U.S. Navy Civilian Divers are indentified as all permanent Navy employees who have 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 who are 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 ensure 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:

6-8.9.1 Scuba Diving (Air) Restriction.

1. Scuba diving shall not be conducted.
   - To depths deeper than 130 fsw
   - To depths deeper than 100 fsw unless a recompression chamber is on station
2. All scuba cylinder manifolds shall be equipped with a manual reserve (J valve), or an independent reserve cylinder gas supply with a separate regulator.
3. A scuba cylinder submersible pressure gauge shall be worn by each diver.

6-8.9.2 Surface Supplied Air Diving Restrictions.

1. Surface Supplied air diving shall not be conducted to depths greater than 190 fsw.

2. Dives shall be limited to in-water decompression times of less than 120 minutes.

3. An emergency gas supply (come-home bottle) is required for any dive greater than 60 fsw planned decompression dives or for which direct access to the surface is not available.

6-8.9.3 Mixed Gas Diving Restrictions.

All mixed gas diving shall be limited to:

- A maximum depth of 220 fsw
- Less than 120 minutes total in-water decompression time
- Having a recompression chamber on station

6-8.9.4 Recompression Chamber Requirements.

1. An on-station recompression chamber is defined as a certified and ready chamber on the dive site.

2. A recompression chamber shall be on station for all planned decompression dives or dives deeper than 100 fsw.

3. Civilian divers shall remain at the location of a manned recompression chamber for 1 hour after surfacing from a dive that requires a recompression chamber on station.

6-9 ORGANIZE AND SCHEDULE OPERATIONS

6-9.1 Task Planning and Scheduling.

All phases of an operation are important. A common failure when planning an operation is to place excessive emphasis on the actual dive phases, while not fully considering pre-dive and post-dive activities. Another failure is to treat operations of a recurring nature with an indifference to safety that comes with over-familiarity. In developing a detailed task-by-task schedule for an operation, the following points shall be considered.

- The schedule shall 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 that shall affect bottom time shall 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 9.

- Plans may include the option to work night and day; however, there is an increased risk of a diving mishap from fatigue.

- The level of personnel support depends on the diving techniques selected (see Minimum Manning Levels, Figure 6-16).

- In planning tasks, non-diving topside support personnel shall 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 shall anticipate difficulties and be prepared to either overcome them or find alternative methods to circumvent them.

- If divers have been inactive and operating conditions permit, work-up dives should be conducted in-water or in the recompression chamber.

6-9.2 **Post-dive Tasks.** A diving operation is completed when the objective has been met, the diving team demobilized, and records and reports are filed. Time shall be allocated for:

- Recovering, cleaning, inspecting, maintaining, repairing, and stowing all equipment

- Disposing 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

6-10 BRIEF THE DIVING TEAM

6-10.1 **Establish Mission Objective.** The Master Diver or the Diving Supervisor shall brief the team on the overall mission and the aspects of the operation necessary to safely achieve the objective. Major points of discussion include:

1. Clear, brief statement of the mission objective

2. Dominant factors that may determine mission outcome (i.e., environment, enemy/friendly actions, and hazards)

3. All tasks required to accomplish the mission

4. Time factors that may prevail

5. Any changes or augmentations of the dive plan

Prior to starting a dive mission or dive day, coordination with other commands and/or shipboard departments shall be accomplished.

6-10.2 **Identify Tasks and Procedures.** A briefing may be elaborate or simple. For complex operations, briefing with charts, slides, and diagrams may be required. For most operations, the briefing need not be complex and may be an informal meeting. The briefing shall present a breakdown of the dive objective, primary tasks, diving procedures, and related work procedures for the mission or dive day. Prompt debriefing of divers returning to the surface provides 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.

6-10.3 **Review Diving Procedures.** Diving and work procedures to be used for the task at hand shall be reviewed during the briefing. The Diving Safety and Planning Checklist (Figure 6-19), Ship Repair Safety Checklist for Diving (Figure 6-20) and the Surface-Supplied Diving Operations Pre-dive Checklist (Figure 6-21) support control of diving operations. These checklists may be tailored to specific missions and environmental circumstances.

6-10.4 **Assignment of Personnel.** All personnel assignments shall be reviewed and verified to ensure properly trained personnel are assigned to operations.

6-10.5 **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 may be accompanied by confusion. The source and availability of any needed assistance and the method for obtaining it as quickly as possible, shall be determined in advance. The location of the nearest recompression chamber shall be identified and the chamber operators notified before the operation begins. The sources of emergency transportation, military or civilian, shall 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 by Figure 6-14, the chamber shall be currently certified and within 30 minutes' travel time from the dive site. If a recompression chamber is required in an emergency, a non-certified chamber may be used if the Diving Supervisor is of the opinion that it is safe to operate.

DIVING SAFETY AND PLANNING CHECKLIST

(Sheet 1 of 4)

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.)

__ **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

Figure 6-19. Diving Safety and Planning Checklist (sheet 1 of 4).

DIVING SAFETY AND PLANNING CHECKLIST

(Sheet 2 of 4)

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 techniques 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 & 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.

__ **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 timeframe.
__ 3. Verify that a completely stocked first aid kit is at hand.
__ 4. If oxygen will be used as standby first aid, verify that the tank is full and properly pressurized, and that 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 that 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 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.

Figure 6-19. Diving Safety and Planning Checklist (sheet 2 of 4).

DIVING SAFETY AND PLANNING CHECKLIST

(Sheet 3 of 4)

__ 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	Near-drowning
Electric shock	Blowup
Entrapment	Lost diver

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 6-7).

__ 5. Designate a Master Diver or properly qualified Diving Supervisor to be in charge of the mission.

__ 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 crew, 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 shall be on hand and shall 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 shall be dressed to the necessary level and ready to enter the water if needed.

__ 3. Assign buddy divers, when required, for all SCUBA operations.

Figure 6-19. Diving Safety and Planning Checklist (sheet 3 of 4).

DIVING SAFETY AND PLANNING CHECKLIST

(Sheet 4 of 4)

__ 4. Take precautions to prevent divers from being fouled on bottom. If work is conducted inside a wreck or other structure, assign a team of divers to accomplish task. One diver enters wreck, the other tends his lines from point of entry.

__ 5. When using explosives, take measures to ensure that no charge shall be fired while divers are in water.

__ 6. Use safety procedures as outlined in relevant Naval publications for all U/W 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.)

__ 9. Ensure that protection against harmful marine life has been provided. (See Appendix 5C.)

__ 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. Command Duty Officer or Commanding Officer of ships alongside

__ 6. Bridge, to ensure that ship's personnel shall not:

- __ turn the propeller or thrusters
- __ get underway
- __ activate active sonar or other electronics
- __ drop heavy items overboard
- __ shift the moor

__ 7. Ship Duty Officer, to ensure that ship's personnel shall 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 recompression chambers and sources of emergency transportation that diving operations are underway and their assistance may be needed.

Figure 6-19. Diving Safety and Planning Checklist (sheet 4 of 4).

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	4. OODs of ships alongside
2. Engineering Officer	5. Squadron Operations (when required)
3. CDO	6. Combat Systems Officer (when required)

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 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 less 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 shall determine if the sea suction is a safety hazard to the divers prior to conducting any diving operation. In all cases the Diving Supervisor shall 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.

NOTIFY KEY PERSONNEL.

1.	OOD	______________________	(signature)
2.	Engineering Officer	______________________	(signature)
3.	CDO	USS ____________________	(signature)
4.	OOD	USS ____________________	
	OOD	USS ____________________	
	OOD	USS ____________________	
	OOD	USS ____________________	
5.	Squadron Operations	______________________	
6.	Port Services Officer	______________________	
		(Diving Supervisor (Signature)	

Figure 6-20. Ship Repair Safety Checklist for Diving (sheet 1 of 2).

SHIP REPAIR SAFETY CHECKLIST FOR DIVING

(Sheet 2 of 2)

TAG OUT EQUIPMENT

TAG OUT	SIGNATURE AND RATE
Rudder	______________________
Anchors	______________________
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)

CDO ______________________

(signature of CDO)

Figure 6-20. Ship Repair Safety Checklist for Diving (sheet 2 of 2).

SURFACE-SUPPLIED DIVING OPERATIONS PREDIVE CHECKLIST

(Sheet 1 of 3)

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 is onsite for all decompression dives deeper than 130 fsw.

__ 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 Protection:

__ 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 harnesses, laces, strain reliefs, and lanyards for wear; renew as needed.

C. 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.

D. 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.

E. 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.

F. Preparing the Diving System:

__ 1. Check that a primary and suitable back-up air 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 diving system operating procedures have been conducted to properly align the dive system.

__ 3. Ensure that qualified personnel are available to operate and stand watch on the dive system.

Figure 6-21. Surface-Supplied Diving Operations Predive Checklist (sheet 1 of 3).

SURFACE-SUPPLIED DIVING OPERATIONS PREDIVE CHECKLIST

(Sheet 2 of 3)

__ 4. Compressors:
- ___ a. Determine that sufficient fuel, coolant, lubricants, and antifreeze 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 all diving system operating procedures have been conducted properly to align the dive system.
- ___ 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.
- ___ e. Ensure that compressor is secure in diving craft and shall not be subject to operating angles, caused by roll or pitch, that will exceed 15 degrees from the horizontal.
- ___ f. Verify that oil in the compressor is an approved type. 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 a clear suction if necessary.
- ___ i. Check all filters, cleaners and oil separators for cleanliness IAW PMS.
- ___ j. Bleed off all condensed moisture from filters and from the bottom of volume tanks. Check all manifold drain plugs, and that all petcocks are closed.
- ___ k. Check that all belt-guards are properly in place on drive units.
- ___ l. Check all pressure-release valves, check valves and automatic unloaders.
- ___ m. 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.
- ___ n. Verify that all pressure supply hoses have safety lines and strain reliefs properly attached.

H. Activate the Air Supply in accordance with approved OPs.

__ 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. Verify that there is a properly functioning pressure gauge on the air receiver and that the compressor is meeting its delivery requirements.

__ 2. Cylinders:
- ___ a. Gauge all cylinders for proper pressure.
- ___ b. Verify availability and suitability of reserve cylinders.
- ___ c. Check all manifolds and valves for operation.
- ___ d. Activate and check delivery.

__ 3. For all supply systems, double check “Do Not Touch” tags (tags outs).

Figure 6-21. Surface-Supplied Diving Operations Predive Checklist (sheet 2 of 3).

SURFACE-SUPPLIED DIVING OPERATIONS PREDIVE CHECKLIST

(Sheet 3 of 3)

I. Diving Hoses:

__ 1. Ensure all hoses have a clear lead and are protected from excessive heating and damage.
__ 2. Check hose in accordance with PMS.
__ 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 shall be part of an operational diving hose.
__ 4. Check that hoses are free of moisture, packing material, or chalk.
__ 5. Soap test hose connections after connection to air supply and pressurization.
__ 6. Ensure umbilical boots are in good condition.

J. Test Equipment with Activated Air Supply in accordance with approved OPs.

__ 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.

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.

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 6-21. Surface-Supplied Diving Operations Predive Checklist (sheet 3 of 3).

Figure 6-22 is a suggested format for the Emergency Assistance Checklist that shall be completed and posted at the diving station to provide necessary information so that any member of the team could take prompt action.

6-10.6 **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.

6-10.7 **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 shall 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 shall remain calm, analyze the situation, and carefully try to work free. Panic and overexertion 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 may be furnished air by the dive partner.

Once the diver has been freed and returns to the surface, the diver shall 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.

6-10.8 **Equipment Failure.** With well-maintained equipment that is thoroughly inspected and tested before each dive, operational failure is rarely 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.

6-10.8.1 **Loss of Gas Supply.** Usually, when a diver loses breathing gas it should be obvious almost immediately. Some diving apparatus configurations may have an emergency gas supply (EGS). When breathing gas is interrupted, the dive shall be

EMERGENCY ASSISTANCE CHECKLIST

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	
Location	
Name/Phone Number	
Response Time	

EMERGENCY CONSULTATION
Duty Phone Numbers 24 Hours a Day
Navy Experimental Dive Unit (NEDU)

Commercial	(850) 234-4351
	(850) 230-3100
DSN	436-4351

Navy Diving Salvage and Training Center (NDSTC)

Commercial	(850) 234-4651
DSN	436-4651

Figure 6-22. Emergency Assistance Checklist.

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.

6-10.8.2 **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 sound is 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.

6-10.9 Lost Diver. In planning for an operation using SCUBA, lost diver procedures shall be included in the dive plan and dive brief. Losing contact with a SCUBA diver can be the first sign of a serious problem. If contact between divers is lost, each diver shall surface. If the diver is not located quickly, or not found at the surface, the Diving Supervisor shall initiate search procedures immediately. At the same time, medical personnel should be notified and the recompression chamber team alerted.

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.

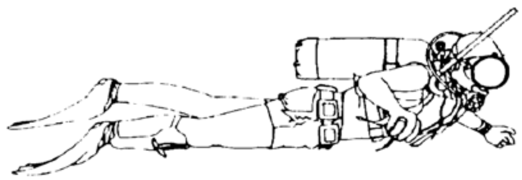
If the diver is found unconscious, attempts should be made to resupply breathing gas and restore consciousness. If this cannot be accomplished, the diver shall be brought to the surface immediately. Gas Embolism may occur during ascent and significant decompression may be missed and immediate recompression may be required. 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.

6-10.10 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 help clarify any confusion that may have arisen because of faulty communications, lack of dive site information, or misunderstandings from the initial briefing.

6-11 AIR DIVING EQUIPMENT REFERENCE DATA

There are several diving methods which are characterized by the diving equipment used. The following descriptions outline capabilities and logistical requirements for various air diving systems.

SCUBA General Characteristics



Principle of Operation:

Self contained, open-circuit demand system

Minimum Equipment:

1. Open-circuit SCUBA with J-valve or submersible pressure gauge
2. Life preserver/buoyancy compensator
3. Weight belt (if required)
4. Dive knife
5. Face mask
6. Swim fins
7. Submersible wrist watch
8. Depth gauge

Principal Applications:

1. Shallow water search
2. Inspection
3. Light repair and recovery

Advantages:

1. Rapid deployment
2. Portability
3. Minimum support requirements
4. Excellent horizontal and vertical mobility
5. Minimum bottom disturbances

Disadvantages:

1. Limited endurance (depth and duration)
2. Limited physical protection
3. Influenced by current
4. Lack of voice communication (unless equipped with a through-water communications system or full face mask)

Restrictions:

Work limits:

1. Normal 130 fsw
2. Maximum 190 fsw with Commanding Officer or Officer-in-Charge's permission
3. 100 fsw using single SCUBA cylinder with less than 100 SCF
4. Standby diver with at least 100 SCF cylinder capacity below 60 fsw
5. Within no-decompression limits
6. Current - 1 knot maximum. Current greater than 1 knot, requires ORM analysis. As a minimum the divers(s) must be tended or have a witness float.

Operational Considerations:

1. Standby diver required
2. Small craft is mandatory for diver recovery during open-ocean diving, when diving off of a large platform or when the diver is untended and may be displaced from dive site, e.g., during a bottom search in a strong current or a long duration swim.
3. Moderate to good visibility preferred
4. Ability to free ascend to surface required (see paragraph 7-8.2)

Figure 6-23. SCUBA General Characteristics.

MK 20 MOD 0 General Characteristics

Principle of Operation:

Surface-supplied, open-circuit lightweight system

Minimum Equipment:

1. MK 20 MOD 0 mask
2. Harness
3. Weight belt (as required)
4. Dive knife
5. Swim fins or boots
6. Surface umbilical

Principal Applications:

Diving in mud tanks and enclosed spaces

Advantages:

1. Unlimited by air supply
2. Good horizontal mobility
3. Voice and/or line-pull signal capabilities

Disadvantages:

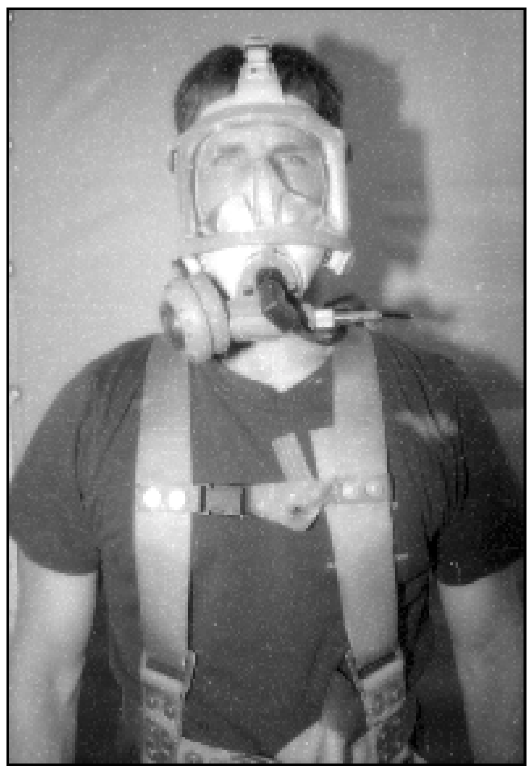
1. Limited physical protection

Restrictions:

1. Work limits: 60 fsw
2. Current - Above 1.5 knots requires extra weights
3. Enclosed space diving requires an Emergency Gas Supply (EGS) with 50 to 150 foot whip and second-stage regulator.

Operational Considerations:

1. Adequate air supply system required
2. Standby diver required



MK 20 MOD 0 Helmet.

Figure 6-24. MK 20 MOD 0 General Characteristics.

MK 21 MOD 1 General Characteristics

Principle of Operation:

Surface-supplied, open-circuit system

Minimum Equipment:

1. MK 21 MOD 1 Helmet
2. Harness
3. Weight belt (if required)
4. Dive knife
5. Swim fins or boots
6. Surface umbilical
7. EGS bottle deeper than 60 fsw

Principal Applications:

1. Search
2. Salvage
3. Inspection
4. Underwater Ships Husbandry and enclosed space diving

Advantages:

1. Unlimited by air supply
2. Head protection
3. Good horizontal mobility
4. Voice and/or line pull signal capabilities
5. Fast deployment

Disadvantages:

1. Limited mobility

Restrictions:

1. Work limits: 190 fsw
2. Emergency air supply (EGS) required deeper than 60 fsw or diving inside a wreck or enclosed space
3. Current - Above 1.5 knots requires extra weights
4. Enclosed space diving requires an Emergency Gas Supply (EGS).

Operational Considerations:

1. Adequate air supply system required
2. Standby diver required

MK 21 MOD 1 Helmet.

Figure 6-25. MK 21 MOD 1 General Characteristics.

EXO BR MS Characteristics

Principle of Operation:

Surface-supplied, open-circuit system
Self contained, open-circuit demand system

Minimum Equipment:

1. EXO BR MS Full Face Mask
2. Manifold Block (except for SCUBA and ship husbandry enclosed spaces)
3. Harness
4. Weight belt (if required)
5. Dive knife
6. Swim fins or boots
7. Surface umbilical
8. EGS bottle deeper than 60 fsw

Principal Applications:

1. Search
2. Salvage
3. Inspection
4. Underwater Ships Husbandry and enclosed space diving

Advantages:

1. Unlimited by air supply
2. Good horizontal mobility
3. Voice and/or line pull signal capabilities
4. Fast deployment

Disadvantages:

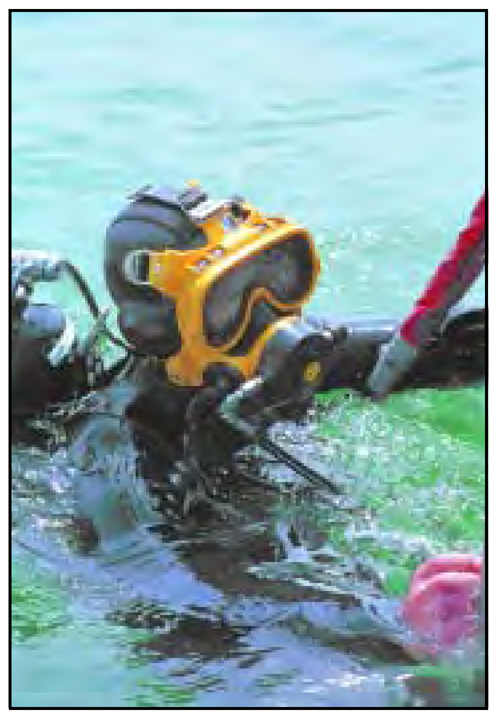
1. Limited physical protection

Restrictions:

1. Work limits: 190 fsw
2. Emergency air supply (EGS) required deeper than 60 fsw or diving inside a wreck or enclosed space
3. Current - Above 1.5 knots requires extra weights
4. Enclosed space diving requires an Emergency Gas Supply (EGS) with 50 to 150 foot whip and second stage regulator.

Operational Considerations:

1. Adequate air supply system required
2. Standby diver required



EXO BR MS Full Face Mask.

Figure 6-26. EXO BR MS Characteristics

CHAPTER 7
SCUBA Air Diving Operations

7-1 INTRODUCTION

7-1.1 **Purpose.** The purpose of this chapter is to familiarize divers with standard and emergency procedures when diving with SCUBA equipment.

7-1.2 **Scope.** This chapter covers the use of open-circuit SCUBA, which is normally deployed in operations not requiring decompression. 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 4.

7-2 REQUIRED EQUIPMENT FOR SCUBA OPERATIONS

At a minimum, each diver must be equipped with the following items to safely conduct an open-circuit SCUBA dive:

- Open-circuit SCUBA.
- Face mask.
- Life preserver/buoyancy compensator.*
- Weight belt and weights as required.**
- Knife.**
- Swim fins.
- Submersible pressure gauge or Reserve J-valve.
- Submersible wrist watch. Only one is required when diving in pairs with a buddy line.**
- Depth gauge. **
- Octopus. ***

* 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.

** These items are not required for the pool phase of SCUBA training.

*** At Commanding Officers discretion based on ORM

7-2.1 **Equipment Authorized for Navy Use.** Only diving equipment that has been certified or authorized for use by the NAVSEA/00C ANU list 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. A current copy must be maintained by all diving activities. The ANU list can be found on the Internet at http://www.navsea.navy.mil/sea00c/doc/anu_disc.html.

7-2.2 **Open-Circuit SCUBA.** All open-circuit SCUBA authorized for Navy use employ a demand system that supplies air each time the diver inhales. The basic open-circuit SCUBA components are:

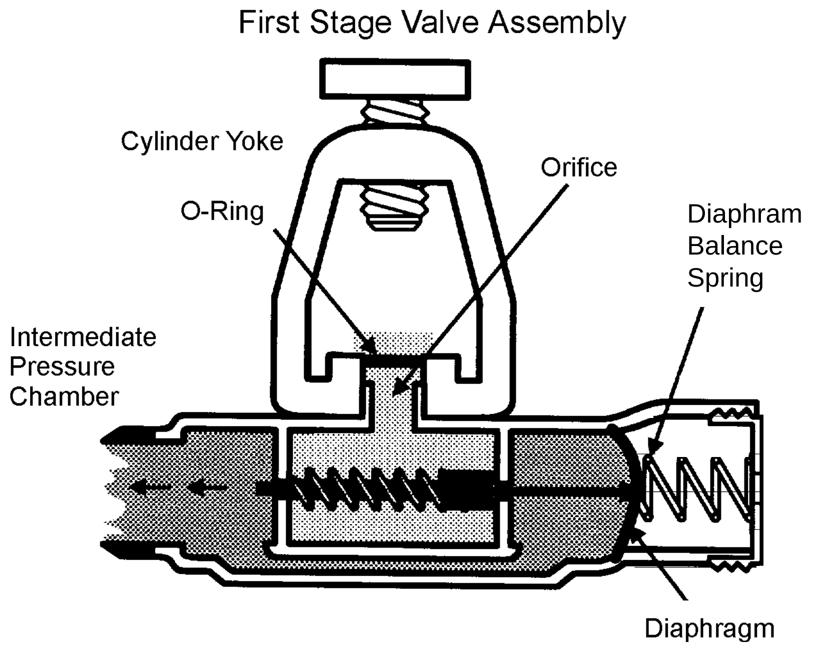
- Demand regulator assembly
- One or more air cylinders
- Cylinder valve and manifold assembly
- Backpack or harness

7-2.2.1 **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 7-1).

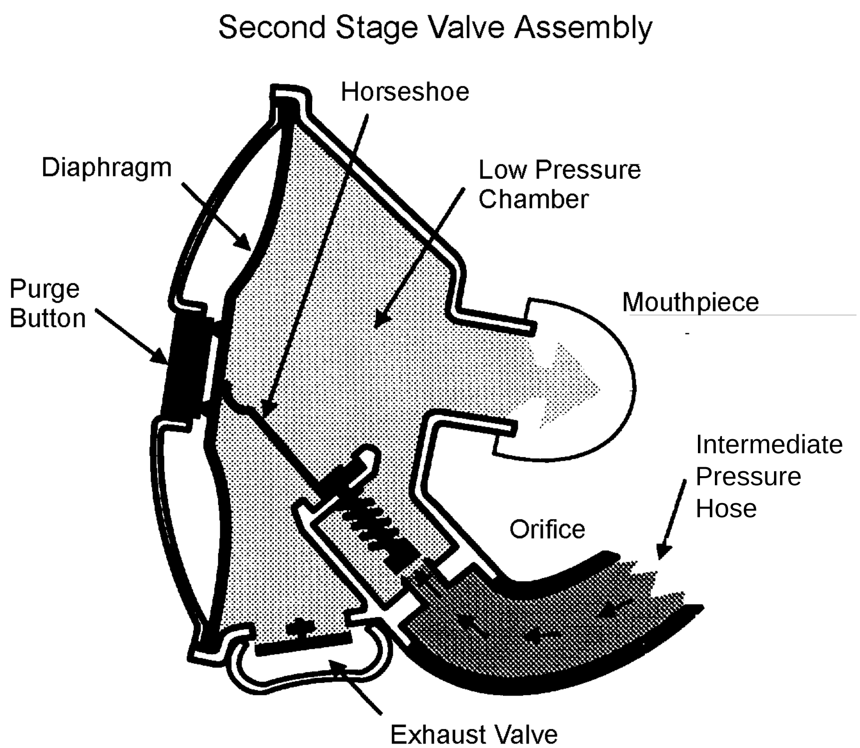
7-2.2.1.1 ***First Stage.*** In the regulator's first stage, high-pressure air from the cylinder passes through a regulator that reduces the pressure of the air to a predetermined level over ambient pressure. Refer to the regulator technical manual for the specific setting.

7-2.2.1.2 ***Second Stage.*** 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 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 air passes through at least one check valve and vents to the water.

7-2.2.1.3 ***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. 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



First Stage. High pressure air flows through the orifice 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 stage assembly closes.



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 orifice 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 in closed. Expired air is dumped from the low pressure chamber to the surrounding water through the exhaust valve.

Figure 7-1. Schematic of Demand Regulator.

system provides guidance for repairing and maintaining SCUBA regulators, the manufacturer's service manual should be followed for specific procedures.

7-2.2.1.4 ***Full Face Mask.*** The AGA/Divator-IIG/MK20 full face 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 the NAVSEA/00C ANU list (Figure 7-2).

Figure 7-2. Full Face Mask.

7-2.2.1.5 ***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.

7-2.2.1.6 ***Octopus.*** An octopus is an additional single hose second stage regulator connected to the diver's first stage regulator and may be used in case the diver's primary second stage regulator fails or for buddy breathing. The octopus must be an ANU approved second stage regulator. Hose length and designation markings are at the discretion of the diving supervisor. An octopus is mandatory for the standby divers. Use of an octopus is the preferred method to accomplish buddy breathing (see paragraph 7-7.7). During predive inspection, the diver shall breathe the octopus to ensure it is working properly.

7-2.2.2 **Cylinders.** SCUBA cylinders (tanks or bottles) are designed to hold high pressure compressed air. 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 7-3).

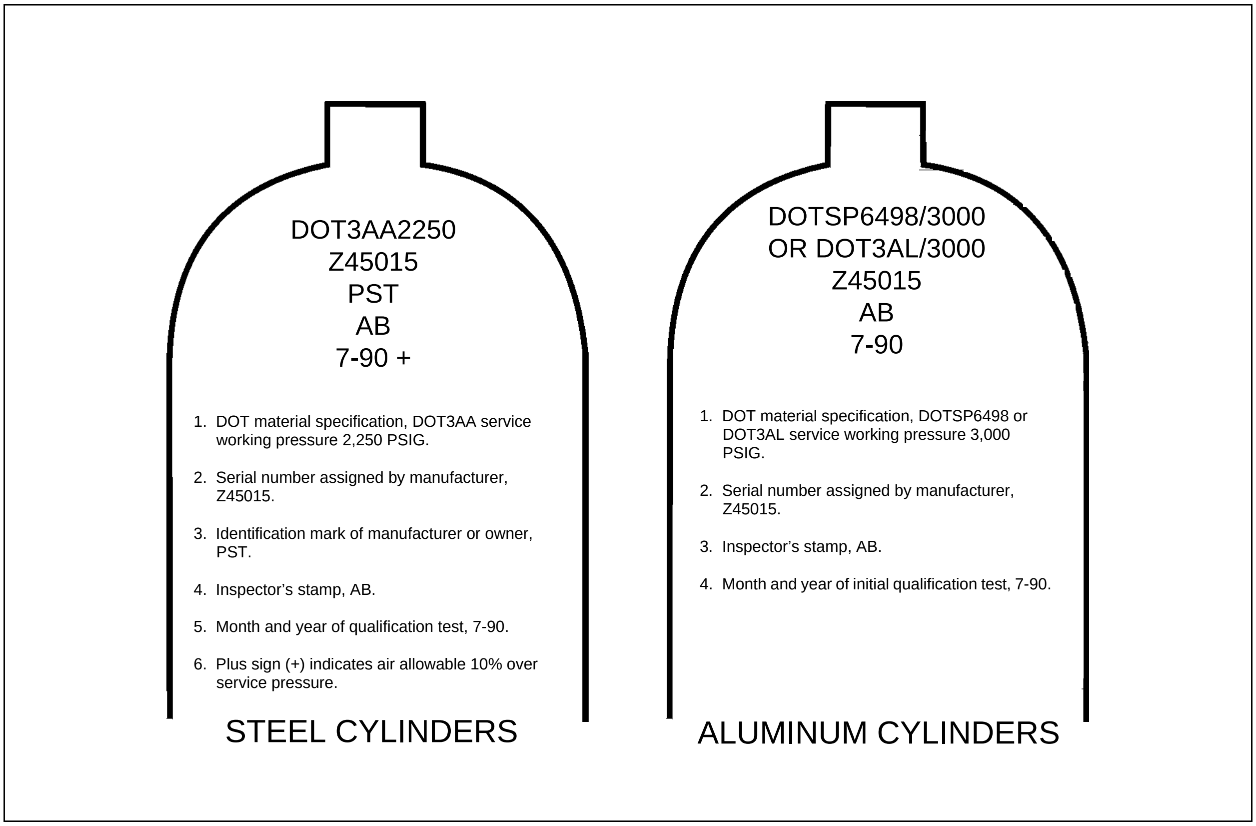


Figure 7-3. Typical Gas Cylinder Identification Markings.

7-2.2.2.1 ***Sizes of Approved SCUBA Cylinders.*** 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 7-1 lists the sizes of some standard SCUBA cylinders. Refer to the NAVSEA/00C ANU list for a list of approved SCUBA cylinders.

Table 7-1. *Sample SCUBA Cylinder Data.*

Open-Circuit Cylinder Description (Note 1)	Rated Working Pressure (PSIG)	Floodable Volume (Cu.Ft.)	Absolute Air Capacity at Rated Pressure (Cu.Ft.)	Reserve Pressure
Steel 72	2,250	0.420	64.7	500
Steel 100	3,500	0.445	106.4	500
Steel 120	3,500	0.526	125.7	500
Aluminum 50	3,000	0.281	48.5	500

Table 7-1. *Sample SCUBA Cylinder Data.*

Open-Circuit Cylinder Description (Note 1)	Rated Working Pressure (PSIG)	Floodable Volume (Cu.Ft.)	Absolute Air Capacity at Rated Pressure (Cu.Ft.)	Reserve Pressure
Aluminum 63	3,000	0.319	65.5	500
Aluminum 80	3,000	0.399	81.85	500
Aluminum 100	3,300	0.470	105.9	500

Note 1: Fifty cubic feet is the minimum size SCUBA cylinder authorized. SEAL teams are authorized smaller cylinders for special operations.

7-2.2.2.2 ***Inspection Requirements.*** Open-circuit SCUBA cylinders must be visually 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 the NAVSEA/00C ANU list, 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.

7-2.2.2.3 ***Guidelines for Handling Cylinders.*** 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, "Compressed Gas Handling." 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 7-4.5. 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.

7-2.2.3 **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.

7-2.2.3.1 ***Blowout Plugs and Safety Discs.*** The cylinder valve contains a high-pressure blowout plug or safety disc plug in the event of excessive pressure buildup. When a dual manifold is used, two blowout plugs or safety disc plugs are installed as specified by the manufacturers' technical manual.

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.

7-2.2.3.2 ***Manifold Connectors.*** If two or more cylinders are to be used together, a manifold unit is needed to provide the necessary interconnection. 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.

7-2.2.3.3 ***Pressure Gauge Requirements.*** 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 alerts the diver that the available air supply is almost exhausted and provides the diver with sufficient reserve air to reach the surface. The air reserve mechanism contains a spring-loaded check valve. When it becomes increasingly difficult to obtain a full breath, the diver must reach over the left shoulder and push down the 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.**

7-2.2.4 **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 diver can remove the cylinder and leave it behind in an emergency.

7-2.3 Minimum Equipment.

7-2.3.1 **Face Mask.** The face mask protects the diver's eyes and nose from the water. Additionally, 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 that provides a wide, clear range of vision.

7-2.3.2 **Life Preserver.** 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 face-up position (Figure 7-4). 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.

All models used by the Navy must be authorized by NAVSEA/00C Authorized for Navy Use List and have a manual inflation device in addition to the low pressure inflation device. 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 use of certain closed and semi-closed UBAs will require the wearing of a life preserver.

Figure 7-4. MK-4 Life Preserver.

The life preserver must be sturdy enough to 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.

7-2.3.3 **Buoyancy Compensator.** When a life preserver is not required by a specific UBA, a buoyancy compensator may be used at the Diving Supervisor's discretion. 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. A list of approved buoyancy compensators is contained in the NAVSEA/00C Authorized for Navy Use List (ANU). Additionally, commands wishing to use BC's that are not on the ANU list, may approve Commercial Off the Shelf (COTS) BC's for use. Approval must be documented with the following guidelines:

- Must have 10 pounds positive lift at maximum depth
- Must have power Inflator and oral inflation device
- Must have Over-inflation device
- Must have releasable weights

Documentation and lift results must be signed by the CO and kept in dive locker for as long as BC is in use at command.

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. Weights installed in a vest type bouyancy compesator must be jettisonable.

Refer to the appropriate technical manual for complete operations and maintenance instructions for the equipment. At the dive supervisor's discretion, when using a variable volume dry suit (VVDS), a Buoyancy Compensator is not required.

CAUTION **Prior to use of VVDS as a buoyancy compensator, divers must be thoroughly familiar with its use.**

7-2.3.4 **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 easily released in the event of an emergency.

Each diver may select the style and size of belt and weights that 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.

7-2.3.5 **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 be also dropped unintentionally.

7-2.3.6 **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.

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.

7-2.3.7 **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.

7-2.3.8 **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.

7-3 OPTIONAL EQUIPMENT FOR SCUBA OPERATIONS

The requirements of a specific diving operation determine which items of optional diving equipment may be necessary. This section lists some of the equipment that may be used.

- Protective clothing
  - Wet suit
  - Variable volume dry suit
  - Gloves
  - Hoods
  - Boots or hard-soled shoes
- Whistle
- Slate and pencil
- Tools and light
- Signal flare
- Tool bag
- Acoustic beacons
- Lines and floats
- Wrist compass
- Witness float
- Snorkel
- Submersible cylinder pressure gauge*
- Chem light and strobe light

NOTE **Submersible cylinder pressure gauge is required when using K valve***

7-3.1 **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. Wet suit, or a dry suit with or without thermal underwear in Figure 7-5 can provide protection.

7-3.1.1 **Wet 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-, 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 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 suit depends upon suit thickness, water temperature, and water depth.

7-3.1.2 **Dry Suits.** The Variable Volume Dry Suit (VVDS) 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

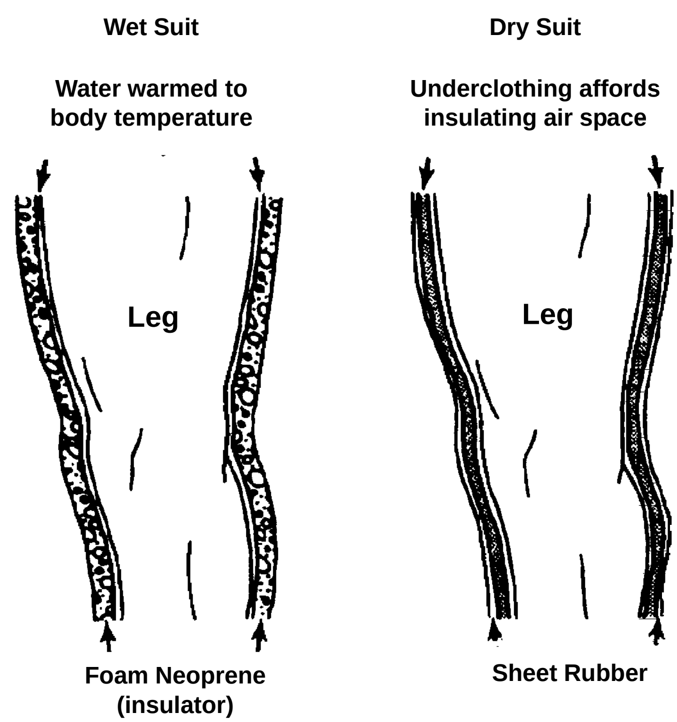


Figure 7-5. Protective Clothing.

used with a wet suit must be carried. Normally, thermal underwear can be worn under the suit for insulation.

7-3.1.3 **Gloves.** 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.

7-3.1.4 **Writing Slate.** A rough-surfaced sheet of acrylic makes an excellent writing slate for recording data, carrying or passing instructions, and communicating between divers. A grease pencil or graphite pencil should be attached to the slate with a lanyard.

7-3.1.5 **Signal Flare.** A signal flare is used to attract attention if the diver has surfaced away from the support crew. Any waterproof flare that can be carried and safely ignited by a diver can be used, but the preferred type is the MK 99 MOD 3 (NSN 1370-01-177-4072; pouch is NSN 1370-01-194-0844). These are day-or-night flares that give off a heavy orange smoke for day time and a brilliant red light at night. Each signal lasts for approximately 45 seconds and will withstand submersion up to depths of 200 fsw without adverse effects. A hexagon shaped end cap marked SMOKE is threaded into the smoke assembly and a round shaped end cap with eight grooves marked FLARE is threaded onto the flare assembly. Also available are the MK 131 MOD 0 (NSN 1370-01-252-0318) and MK 132 MOD 0 (NSN 1370-01-252-0317). The MK 131 is for day time distress signaling while the MK 132 is for night. The only difference between the MK 99 and the MK 131/132, other than the fact that the MK 99 is a combined day/night signal flare which gives off yellow smoke and light, is that the MK 99 satisfies magnetic effect limits of MIL-M-19595 for explosive ordinance disposal (EOD) usage. Flares should be handled with care. For safety, each diver should carry a maximum of two flares. All divers/combat swimmers engaged in submarine Dry Deck Shelter operations should stow flares in hangar prior to reentering the host submarine.

7-3.1.6 **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.

7-3.1.7 **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 hand-hold 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 diver 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 a lifeline to the diver, never to a piece of equipment that may be ripped away or may be removed in an emergency.

7-3.1.8 **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 to the opposite side of the regulator.

7-3.1.9 **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 6 months.

7-3.1.10 **Submersible Cylinder Pressure Gauge.** The submersible cylinder pressure gauge provides the diver with a continual read-out of the air remaining in the cylinder(s). Various submersible pressure gauges suitable for Navy use are commercially available. Most are equipped with a 2- to 3-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.

7-4 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.

7-4.1 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, which varies with the diver's work rate,
- The depth of the dive, and
- The capacity and minimum pressure of the cylinder(s).

Temperature is usually not significant in computing the duration of the air supply, unless the temperature conditions are extreme. When diving in extreme temperature conditions, Charles'/Gay-Lusac's law must be applied.

There are three steps in calculating how long a diver's air supply will last:

1. Calculate the diver's consumption rate by using this formula:

$$C = \frac{D + 33}{33} \times RMV$$

Where:

C	=	Diver's consumption rate, standard cubic feet per minute (scfm)
D	=	Depth, fsw
RMV	=	Diver's Respiratory Minute Volume, actual cubic feet per minute (acfm) (from Figure 3-6)

2. Calculate the available air capacity provided by the cylinders. The air capacity must be expressed as the capacity that will actually be available to the diver, rather than as a total capacity of the cylinder. The formula for calculating the available air capacity is:

$$V_a = \frac{P_c \angle P_m}{14.7} \times FV \times N$$

Where:

P_c	=	Measured cylinder pressure, psig
P_m	=	Minimum pressure of cylinder, psig
FV	=	Floodable Volume (scf)
N	=	Number of cylinders
V_a	=	Capacity available (scf)

3. Calculate the duration of the available capacity (in minutes) by using this formula:

$$\text{Duration} = \frac{V_a}{C}$$

Where:

V_a	=	Capacity available, scf
C	=	Consumption rate, scfm

Sample Problem. 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 2,250 psig.

1. Calculate the diver's consumption rate in scfm. According to Figure 3-6, the diver's consumption rate at depth is 1.4 acfm.

$$C = \frac{D + 33}{33} \times RMV$$

$$= \frac{70 + 33}{33} \times 1.4$$

$$= 4.37 \text{ scfm}$$

2. Calculate the available air capacity provided by the cylinders. Table 7-1 contains the cylinder data used in this calculation:

- Floodable Volume = 0.420 scf
- Rated working pressure = 2250 psig
- Reserve pressure for twin 72-cubic-foot cylinders = 250 psig

$$V_a = \frac{P_c \angle P_m}{14.7} \times FV \times N$$

$$= \frac{2250 \angle 250}{14.7} \times 0.420 \times 2$$

$$= 114 \text{ scf}$$

3. Calculate the duration of the available capacity.

$$\text{Duration} = \frac{V_a}{C}$$

$$= \frac{114 \text{ scf}}{4.37 \text{ scfm}}$$

$$= 26 \text{ minutes}$$

The total time for the dive, from initial descent to surfacing at the end of the dive, is limited to 26 minutes.

7-4.2 **Compressed Air from Commercial Sources.** 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 Source I or Source II air as specified by FED SPEC BB-A-1034B. Refer to Table 4-2 in Chapter 4 for the air purity requirements.

7-4.3 Methods for Charging SCUBA Cylinders.

NOTE **Paragraph 7-4.5 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. The NAVSEA/00C ANU list lists approved high-pressure compressors and equipment authorized for SCUBA air sources.

The normal cascade system consists of supply flasks connected together by a manifold and feeding into a 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 7-6.

SCUBA charging lines shall be fabricated using SAE 100R7 hose for 3,000 psi service and SAE 100R8 hose for 5,000 psi service. The service pressure of the

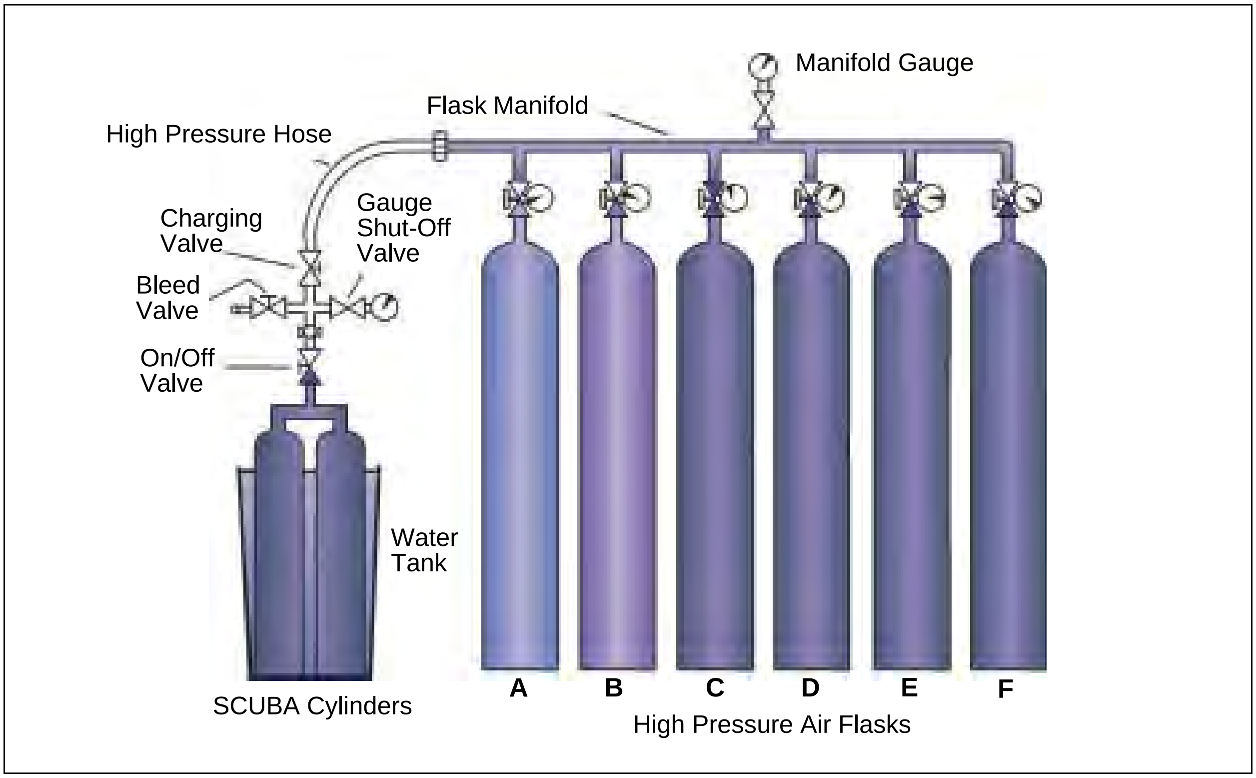


Figure 7-6. Cascading System for Charging SCUBA Cylinders.

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 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 18 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 shall be 1/8-inch nylon or material of equivalent strength. Tie wraps, tape, and marlin are not authorized for this purpose.

7-4.4 **Operating Procedures for Charging SCUBA Tanks.** Normally, SCUBA tanks are charged using the following operating procedures (OPs), which may be tailored to each unit:

1. Determine that the cylinder is within the hydrostatic test date.

2. Check the existing pressure in the SCUBA cylinder with an accurate pressure gauge.

3. Attach the cylinder to the yoke fitting on the charging whip, and attach the safety strain relief.

4. For safety and to dissipate heat generated in the charging process, when facilities are available, 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.

5. Tighten all fittings in the system.

6. Close the bleed valve.

7. Place reserve mechanism lever in the open (lever down) position.

8. Open the cylinder (on/off) valve. This valve is fully opened with about two turns on the handle, counter-clockwise. 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 back off one-quarter to one-half turn. This will not impede the flow of air.

9. Open the supply flask valve.

10. Slowly open the charging valve. The sound of the air flowing into the SCUBA cylinder is noticeable. The operator will 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.

11. Monitor the pressure gauge carefully. When the reading reaches the rated pressure for the SCUBA cylinder, close the valve on the first cylinder and take a reading.

12. Close the charging valve.

13. Close the on/off valve on the SCUBA cylinder.

14. Ensure that all valves in the system are firmly closed.

15. Let the SCUBA cylinder cool to room temperature. Once the cylinder is cool, the pressure will have dropped and you may need to top off the SCUBA cylinder.

7-4.4.1 **Topping off the SCUBA Cylinder.** Follow this procedure to top off a SCUBA cylinder:

1. Open the on/off valve on the SCUBA cylinder.
2. Select a supply flask with higher pressure than the SCUBA rated limit.
3. Open the supply valve on the flask.
4. Throttle the charging valve to bring the SCUBA cylinder up to the rated limit.
5. Close all valves.
6. Open the bleed valve and depressurize the lines.
7. When air has stopped flowing through the bleed valve, disconnect the SCUBA cylinder from the yoke fitting.
8. Reset the reserve mechanism (lever in up position).

In the absence of high-pressure air systems, large-volume air compressors can be used to charge SCUBA cylinders directly. However, few compressors can deliver 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 when using air compressors are:

- The compressor must be listed in the NAVSEA/00C ANU list if it is not part of a certified system.
- The compressor must deliver air that 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 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 in accordance with PMS procedures or manufacturer's recommendations.

Additional information on using air compressors is found in paragraph 8-7.2.2.

7-4.5 **Safety Precautions for Charging and Handling Cylinders.** The following safety rules apply to charging and handling SCUBA cylinders:

- 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 accidentally tripped or the straps may fail.

- Do not attempt to fill any cylinder if the hydrostatic test date has expired or if 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. See CGA Pamphlet C-6, Standards for Visual Inspection of Compressed Gas Cylinders.

- Always use gauges to measure cylinder pressure. Never point the dial of a gauge to which pressure is being applied toward the operators face.

- Never work on a cylinder valve while the cylinder is charged.

- Make sure that the air reserve mechanism is open (lever down) before charging.

- Use only compressed air for filling conventional SCUBA cylinders. Never fill SCUBA cylinders with oxygen. Air is color-coded black, while oxygen is color-coded green.

- Tighten all fittings before pressurizing lines.

- When fully charged, close the air reserve (lever up). Mark the filled tank to indicate the pressure to which it was charged.

- Handle charged cylinders with care. If a charged cylinder is damaged or if the valve is accidentally 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.

- Store filled cylinders in a cool, shaded area. Never leave filled cylinders in direct sunlight.

- Cylinders should always be properly secured aboard ship or in a diving boat.

7-5 PREDIVE PROCEDURES

Predive procedures for SCUBA operations include equipment preparation, diver preparation, and conducting a predive inspection before the divers enter the water.

7-5.1 Equipment Preparation. Prior to any dive, all divers must carefully inspect their own equipment for signs of deterioration, damage, or corrosion. The equipment must be tested for proper operation. Predive preparation procedures must be standardized, not altered for convenience, and must be the personal concern of each diver.

7-5.1.1 **Air Cylinders.**

- Inspect air cylinder exteriors and valves for rust, cracks, dents, and any evidence of weakness.

- 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.

  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 must 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.

  5. When the gauge reads zero, remove the gauge from the cylinder.

  6. Close the air reserve mechanism (lever in up position).

  7. 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.

7-5.1.2 **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.

7-5.1.3 **Breathing Hoses.**

- Check the hoses 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 and in accordance with PMS procedures.

7-5.1.4 **Regulator.**

1. Ensure over-bottom pressure of first stage regulator has been set to a minimum of 135 psig or in accordance with manufacturer's recommendations within the past year.

2. Attach regulator to the cylinder manifold, ensuring that the O-ring is properly seated.

3. Crack the cylinder valve open and wait until the hoses and gauges have equalized.

4. Next open the cylinder valve completely and then close (back off) one-quarter turn.

5. 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.

7-5.1.5 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 shall 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.

7-5.1.6 Face Mask.

- Check the seal of the mask and the condition of the head strap.

- Check for cracks in the skirt and faceplate.

7-5.1.7 Swim Fins.

- Check straps for signs of cracking.

- Inspect blades for signs of cracking.

7-5.1.8 Dive Knife.

- Test the edge of the knife for sharpness.
- Ensure the knife is fastened securely in the scabbard.
- Verify that the knife can be removed from the scabbard without difficulty, but will not fall out.

7-5.1.9 **Snorkel.**

- Inspect the snorkel for obstructions.
- Check the condition of the mouthpiece.

7-5.1.10 **Weight Belt.**

- Check the condition of the weight belt.
- Make sure that the proper number of weights are secure and in place.
- Verify that the quick-release buckle is functioning properly.

7-5.1.11 **Submersible Wrist Watch.**

- Ensure wrist watch is wound and set to the correct time.
- Inspect the pins and strap of the watch for wear.

7-5.1.12 **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.

7-5.1.13 **Miscellaneous Equipment.**

- Inspect any other equipment that 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.

7-5.2 **Diver Preparation and Brief.** When the divers have completed inspecting and testing their equipment, they shall report to the Diving Supervisor. The divers shall be given a predive briefing of the dive plan. This briefing is critical to the success and safety of any diving operation and shall 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 (e.g., unconscious diver, trapped diver, loss of air, 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.

7-5.3 **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 recommended dressing sequence to be observed:

1. Protective clothing. Ensure adequate protection is provided with a wet suit.
2. Booties 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 tender holding 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 off 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).

7. Weight belt.

8. Gloves.

9. Swim fins.

10. Face mask or full face mask.

7-5.4 **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 buoyancy compensator, weight belt, dive knife, scabbard, swim fins, watch and depth gauge). When diving SCUBA and a buddy line is used, only one depth gauge and one watch per dive team is required.

3. Verify that the cylinders have been gauged and that the available volume of air is sufficient for the planned duration of the dive.

4. Ensure that all quick-release buckles and fastenings can be reached by either hand and are properly rigged for quick release.

5. 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.

6. Verify that the life preserver or buoyancy compensator is not constrained and is free to expand, and that all air has been evacuated.

7. Check position of the knife to ensure that it will remain with the diver no matter what equipment is left behind.

8. Ensure that the cylinder valve is open fully and backed off one-quarter to one-half turn.

9. Ensure that 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.

10. 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.

11. 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.

12. Give the breathing hoses and mouthpiece a final check; ensure that none of the connections have been pulled open during the process of dressing.

13. Check that the air reserve mechanism lever is up (closed position).

14. Conduct a brief final review of the dive plan.

15. Verify that dive signals are displayed and personnel and equipment are ready to signal other vessels in the event of an emergency.

7-6 WATER ENTRY AND DESCENT

The divers are now ready to enter the water, where their SCUBA shall be given another brief inspection by their dive partners or tenders prior to descent.

7-6.1 Water Entry.

Water Entry. There are several ways to enter the water, with the choice usually determined by the nature of the diving platform (Figure 7-7). 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 the 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.

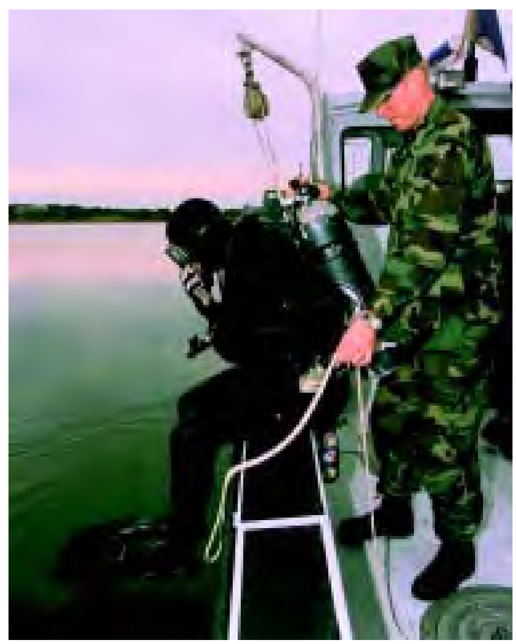
7-6.1.1 **Step-In Method.** The step-in method is the most frequently used, and is best used from a stable platform or vessel. The divers should simply take a large step out from the platform, keeping legs in an open stride. They should try to enter the water with a slightly forward tilt of the upper body so that the force of entry will not cause the cylinder to hit the back of the head.

7-6.1.2 **Rear Roll Method.** The rear roll is the preferred method for entering the water from a small boat. 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 mouth-piece in place, the diver rolls backward, basically moving through a full backward somersault.

Front jump or step-in. On edge of platform, one hand holding face mask and regulator, the other holding the cylinders, the diver takes a long step forward, keeping his legs astride.

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 completing a full backward somersault.

Side roll. Tender assists diver in taking a seated position. Tender stands clear as diver holds his mask and cylinders and rolls into the water.



Front roll. Diver sits on edge of platform with a slight forward lean to offset the weight of the cylinders. Holding his mask and cylinders, the diver leans forward.

Figure 7-7. SCUBA Entry Techniques.

7-6.1.3 **Entering the Water from the Beach.** Divers working from the beach 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. 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 should gradually settle into the waves as the waves break around them.

Rear step-in. The diver steps backward pushing himself away with his feet.

Figure 7-7. 14SCUBA Entry Techniques (continued).

7-6.2 Pre-descent Surface Check. Once in the water, and before 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, with no resistance and 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 (see paragraph 7-7.2).
- 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 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.

7-6.3 **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. When surface swimming with a SCUBA regulator, hold the mouthpiece so that air does not free-flow from the system.

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 by partially inflating the life preserver or buoyancy compensator. However, the preserver must be deflated again before the dive begins.

7-6.4 **Descent.** The divers may swim down or they may use a descending line to 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 should never exceed 75 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 extend an arm to ward off any obstructions.

Upon reaching the operating depth, the divers must orient themselves to their surroundings, verify the site, and check the underwater conditions. If conditions 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.

7-7 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 must monitor the condition of the dive partner constantly.

7-7.1 **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, he should pause in the work until breathing returns to normal. If normal breathing is not restored soon, the diver must signal the dive partner and break off the operation, and together they should ascend to the surface.

Some divers, knowing that they have a limited 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 **Skip-breathing may lead to hypercapnia and shall not be practiced.**

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 submersible bottle gauge, the diver shall monitor his air supply pressure and must terminate the dive whenever bottle pressure is reduced to 500 psi for a single bottle or 250 psi for a set of double bottles.

7-7.2 **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. 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. When the mask has a purge valve, the diver tilts his 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 (see Figure 7-8).

7-7.3 **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.

To clear a double-hose SCUBA regulator that 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 it out through the regulator's exhaust ports. The diver should carefully take a shallow breath. If water is still trapped in the mouthpiece, 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.

7-7.4 **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

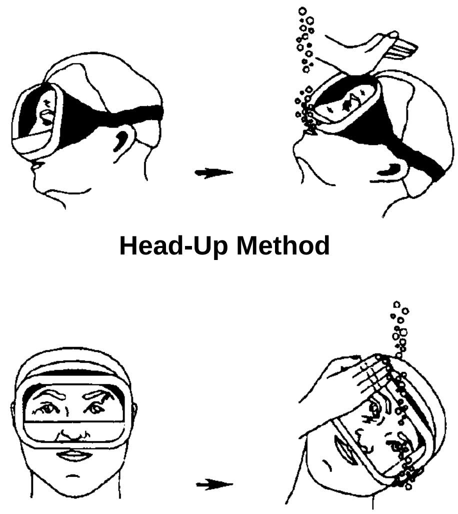


Figure 7-8. Clearing a Face Mask. To clear a flooded face mask, push gently on the upper or side portion of the mask and exhale through the nose into the mask. As water is forced out, tilt the head backward or sideway until the mask is clear.

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.

7-7.5 **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.

7-7.5.1 **Through-Water Communication Systems.** Presently, several types of through-water communication systems are available for SCUBA diving operations. Acoustic systems provide one-way, topside-to-diver communications. The multi-directional audio signal is emitted through the water by a submerged transducer. Divers can hear the audio signal without 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 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, consult the NAVSEA/00C Authorized for Navy Use (ANU) list.

7-7.5.2 **Hand and Line-Pull Signals.** Navy divers shall only use hand signals that have been approved for Navy diving use. Figure 7-9 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 Table 8-3. 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.

7-7.6 **Buddy Diver Responsibilities.** 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 partner 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.
- 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.

7-7.7 **Buddy Breathing Procedure.** If a diver runs out of air or the SCUBA malfunctions, air may be shared with the dive partner. The preferred method of buddy breathing is the use of an octopus. As an alternative, the two divers may face each other and alternately breathe from the same mouthpiece while ascending. Buddy breathing may be used 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 signal the partner by pointing to SCUBA mouthpiece.

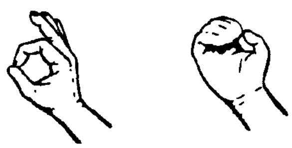
	Meaning/Signal	Comment
	**STOP** Clenched fist.	
	**SOMETHING IS WRONG** Hand flat, fingers together, palm out, thumb down then hand rocking back and forth on axis of forearm.	This is the opposite of Okay. The signal does not indicate an emergency.
	**I AM OKAY or ARE YOU OKAY?** Thumb and forefinger making a circle with three remaining fingers extended (if possible).	Divers wearing mittens may not be able to extend three remaining fingers distinctly. Short range use.
 	**OKAY ON THE SURFACE (CLOSE)** Right hand raised overhead giving Okay signal with fingers. **OKAY ON THE SURFACE (DISTANT)** Both hands touching overhead with both arms bent at 45° angle.	Given when diver is close to pickup boat. Given when diver is at a distance from the pickup boat.
	**DISTRESS or HELP or PICK ME UP** Hand waving overhead (diver may also thrash hand in water).	Indicates immediate aid is required.
	**WHAT TIME? or WHAT DEPTH?** Diver points to either watch or depth gauge.	When indicating time, this signal is commonly used for bottom time remaining.
	**GO DOWN or GOING DOWN** Two fingers up, two fingers and thumb against palm.	
	**GO UP or GOING UP** Four fingers pointing up, thumb against palm.	
 	**I'M OUT OF AIR.** Hand slashing or chopping at throat. **I NEED TO BUDDY BREATHE** Fingers pointing to mouth or regulator.	Indicates signaler is out of air. Signaler's regulator may be in or out of mouth.

Figure 7-9. SCUBA Hand Signals (page 1 of 3).

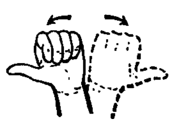
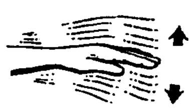
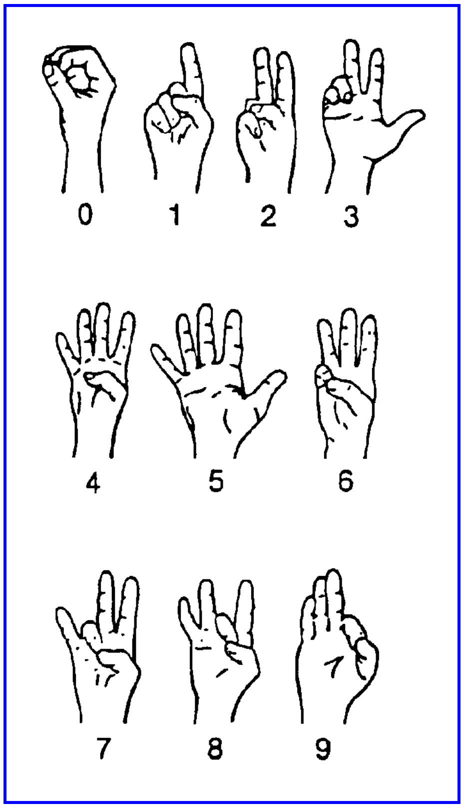
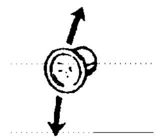
	Meaning/Signal	Comment
	**COME HERE** Hand to chest, repeated.	
	**ME or WATCH ME** Finger to chest, repeated.	
	**OVER, UNDER, or AROUND** Fingers together and arm moving in and over, under, or around movement.	Diver signals intention to move over, under, or around an object.
	**LEVEL OFF or HOW DEEP?** Fingers and thumb spread out and hand moving back and forth in a level position.	
	**GO THAT WAY** Fist clenched with thumb pointing up, down, right, or left.	Indicates which direction to swim.
	**WHICH DIRECTION?** Fingers clenched, thumb and hand rotating right and left.	
	**EAR TROUBLE** Diver pointing to either ear.	Divers should ascend a few feet. If problem continues, both divers must surface.
	**I'M COLD** Both arms crossed over chest.	
	**TAKE IT EASY OR SLOW DOWN** Hand extended, palm down, in short up-and-down motion.	
	**YOU LEAD, I'LL FOLLOW** Index fingers extended, one hand forward of the other.	

Figure 7-9. SCUBA Hand Signals (page 2 of 3).

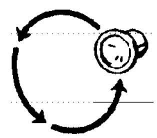


NIGHT DIVING SIGNALS
(Buddy at Distance)

When buddy is near, use regular hand signals in front of light.



Something is wrong.
I require assistance.
(Large, rapid up-and-down motions with arm extended.)



I am Okay.
Are you Okay?
(Large, slow circles with light.)

Figure 7-9. SCUBA Hand Signals (page 3 of 3).

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. The partner gives his octopus to the distressed diver. If an octopus is not available, proceed to step 3.

3. The partner must make the first move by taking a breath and passing the 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, clear the mouthpiece by using 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.**

7-7.8 Tending.

7-7.8.1 **Tending with a Surface or Buddy Line.** When a diver is being tended by 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 Table 8-3.
- 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 2 or 3 minutes to determine that 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.

7-7.8.2 **Tending with No Surface Line.** 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 (such as a pinger or strobe light). When tending a single diver, the tender shall continually monitor the diver float for diver location and line pull signals.

7-7.9 **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 applying force to a wrench, for example, the diver is pushed away and can apply very little torque. 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 that requires leverage or force (including pneumatic power tools), the diver should be braced with feet, a free hand, or a shoulder.

NOTE **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 the NAVSEA/00C ANU list.

7-7.10 **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 to offset the effects of certain underwater conditions:

- Stay 2 or 3 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 the 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 appearing to be 3 feet away is actually 4 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 that are under stress.

7-8 ASCENT PROCEDURES

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 shall 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.

7-8.1 **Emergency Free-Ascent Procedures.** 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. Guidelines for a free ascent are:

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 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.

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. Exhale continuously during ascent to let the expanding air in the lungs escape freely.

7-8.2 **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 EOD operations involving limpet search and neutralization, the use of tending lines is not practical and is not required. During EOD limpet mine training, the use of tending lines is required.

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 search shall 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.

7-8.3 **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 shall 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 9 shall 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, signaling their arrival at the next stop. Stop times will always be regulated by the Dive Supervisor.

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 (Chapter 1 and Chapter 5).

7-8.4 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 buoyancy 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 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 the diver 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.

7-9 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 8
Surface Supplied Air Diving Operations

8-1 INTRODUCTION

8-1.1 **Purpose.** Surface supplied air diving includes those forms of diving where air is supplied from the surface to the diver by a flexible hose. The Navy Surface Supplied Diving Systems (SSDS) are used primarily for operations to 190 feet of seawater (fsw).

8-1.2 **Scope.** This chapter identifies the required equipment and procedures for using the UBA MK 21 MOD 1 and the UBA MK 20 MOD 0 surface supplied diving equipment.

8-2 MK 21 MOD 1

The MK 21 MOD 1 is an open circuit, demand, diving helmet (Figure 8-1). The maximum working depth for air diving operations using the MK 21 MOD 1 system is 190 fsw. The MK 21 MOD 1 system may be used up to 60 fsw without an Emergency Gas Supply (EGS). An EGS is mandatory at depths deeper than 60 fsw and when diving inside a wreck or enclosed space. The Diving Supervisor may elect to use an EGS that can be man-carried or located outside the wreck or enclosed space and connected to the diver with a 50 to 150 foot whip. Planned air dives below 190 fsw require CNO approval.

Figure 8-1. MK 21 MOD 1 SSDS.

8-2.1 **Operation and Maintenance.** The technical manual for the MK 21 MOD 1 is NAVSEA S6560-AG-OMP-010, *Technical Manual, Operation and Maintenance Instructions, Underwater Breathing Apparatus MK 21 MOD 1 Surface Supported Diving System*. 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.

8-2.2 **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 8-7.2.3

8-2.2.1 **Emergency Gas Supply Requirements.** The emergency breathing supply valve provides an air supply path parallel to the nonreturn valve and permits attachment of the EGS whip. The EGS system consists of an adequately charged ANU approved scuba cylinder with either a K- or J- valve (with reserve turned down) and a first stage regulator set at manufacturer's recommended pressure, but not lower than 135 psig. A relief valve set at 180 ± 5 psig 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 pressure gauge is also required on the first stage regulator.

An adequately charged scuba cylinder is defined as the pressure that provides sufficient air to bring the diver to his first decompression stop or the surface for no-decompression dives. It is assumed that this will give topside personnel enough time to perform required emergency procedures to restore umbilical air to the diver.

For enclosed space diving an extended EGS whip 50 to 150 feet in length may be used. If the diving scenario requires the EGS topside, adjust the first stage regulator to 150 psig.

NOTE **For open water dives 60 fsw and shallower, the diving supervisor may use an ANU approved cylinder designated for MK-21 as an emergency air source.**

Sample Problem 1. Determine the minimum EGS cylinder pressure required for a MK-21 MOD 1 dive to 190 fsw for five minutes.

1. To calculate the EGS cylinder pressure, you must first determine the amount of gas required to get the diver back to the stage and leave bottom plus the gas required for ascent to the first decompression stop. The formula for calculating gas required is:

$$V_r = \frac{D + 33}{33} \times 1.4 \times T$$

Where:

V_r	=	Capacity required (scf)
D	=	Depth (fsw)
1.4	=	Consumption rate in acfm per diver from Table 8-2
T	=	Time (minutes)

Air required while on the bottom: For this example, if the time to get the diver to the stage and leave bottom is 3 minutes, then:

$$\text{Bottom } V_r = \frac{190 + 33}{33} \times 1.4 \times 3$$

$$= 28.38 \text{ scf}$$

Air required for ascent to reach the first stop: For this example, you need to determine ascent time and average depth. Ascent time is 7 minutes (rounded up from 6 minutes 20 seconds) from 190 fsw to the surface at 30 feet per minute. Average depth is calculated as follows:

$$\text{average depth} = \frac{190}{2} = 95\text{fsw}$$

$$\text{Ascent } V_r = \frac{95 + 33}{33} \times 1.4 \times 7$$

$$= 38.01 \text{ scf}$$

$$\text{Total } V_r = 28.38 + 38.01$$

$$= 66.39 \text{ scf}$$

2. The next step is to convert the required scf to an equivalent cylinder pressure in psig. In this example, we are using an 80 ft^3 aluminum cylinder to support this dive. Refer to Table 7-1 for cylinder data used in this calculation:

$$\text{psig required} = \frac{V_r}{FV} \times 14.7 + P_m$$

Where:

FV	=	Floodable Volume (scf) = 0.399 scf
14.7	=	Atmospheric Pressure (psi)
P_m	=	Minimum cylinder pressure

Minimum Cylinder Pressure = First stage regulator setting + bottom pressure at final stop: [135 psig + (0 fsw x 0.445 psi)] = 135 psig

$$= \frac{66.39}{0.399} \times 14.7 + 135$$

$$= 2580.95 (\text{round to } 2600 \text{ psig})$$

8-2.2.2 **Flow Requirements.** When the MK 21 MOD 1 system is used, the air supply system must be able to provide an average sustained flow of 1.4 acfm to the diver. The 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 When planning a dive, calculations are based on 1.4 acfm.

To satisfactorily support the MK 21 MOD 1 system, the air supply must:

- Replenish the air consumed from the system (average rate of flow)
- Replenish the air at a rate sufficient to maintain the required pressure
- Provide the maximum rate of flow required by the diver

8-2.2.3 **Pressure Requirements.** Because the MK 21 MOD 1 helmet is a demand type system, the regulator has an optimum overbottom pressure that ensures the lowest possible breathing resistance and reduces the possibility of overbreathing the regulator (demanding more air than is available). For those systems not capable of sustaining 165 psi overbottom due to design limitations, 135 psi overbottom is acceptable. Table 8-1 shows the MK 21 MOD 1 overbottom pressure requirements.

Table 8-1. *MK 21 MOD 1 Over Bottom Pressure Requirements*

Dive Depth	Pressure in psig		
	Minimum	Desired	Maximum
0-60 fsw	90*	135	165
61-130 fsw	135	135	165
131-190 fsw	165**	165	165

* Not approved for use with a double exhaust kit installed. Instead use a minimum of 135 psig.

** For diver life support systems not capable of sustaining 165 psig over bottom due to system design limitations, 135 psig is authorized.

This ensures that the air supply will deliver air at a pressure sufficient to overcome bottom seawater pressure and the pressure drop that occurs as the air flows through the hoses and valves of the mask.

Sample Problem 1. Determine the air supply manifold pressure required to dive the MK 21 MOD 1 system to 175 fsw.

1. Determine the bottom pressure at 175 fsw:

$$\text{Bottom pressure at 175 fsw} = 175 \times .445 \text{ psi}$$
$$= 77.87 \text{ psig (round to 78)}$$

2. Determine the overbottom pressure for the MK 21 MOD 1 system (see Table 8-1). Because the operating depth is 175 fsw, the overbottom pressure is 165 psig.

3. Calculate the minimum manifold pressure (MMP) by adding the bottom pressure to the overbottom pressure:

$$\text{MMP} = 78 \text{ psig} + 165 \text{ psig}$$
$$= 243 \text{ psig}$$

The minimum manifold pressure for a 175 fsw dive must be 243 psig.

Sample Problem 2. Determine 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. There are 5 flasks in the bank; only 4 are on line. Each flask has a floodable volume of 8 cubic feet and is charged to 3,000 psig.

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 consumption over short periods can be expected based on diver work rate.**

1. Calculate minimum manifold pressure (MMP).

$$\begin{aligned}\mathsf{MMP(psig)} &= (0.445\mathsf{D}) + 165\ \mathsf{psig} \\ &= (0.455 \times 130) + 165\ \mathsf{psig} \\ &= 222.85\ \mathsf{psig}\end{aligned}$$

Round up to 223 psig

2. Calculate standard cubic feet (scf) of air available. The formula for calculating the scf of air available is:

$$\text{scf available} = \frac{\mathsf{P_f} \angle (\mathsf{P_{mf}} + \mathsf{MMP})}{14.7} \times \mathsf{FV} \times \mathsf{N}$$

Where:

P_f	=	Flask pressure = 3,000 psig
P_{mf}	=	Minimum flask pressure = 200 psig
MMP	=	223 psig
FV	=	Floodable Volume of flask = 8 scf
N	=	Number of flasks = 4

$$\begin{aligned}\text{scf available} &= \frac{3000 \angle (200 + 223)}{14.7} \times 8 \times 4 \\ &= 5609.79\ \text{scf (round down to 5600)}\end{aligned}$$

3. Calculate scf of air required to make the dive. You will need to calculate the air required for the bottom time, the air required for each decompression stop, and the air required for the ascent. The formula for calculating the air required is:

$$\text{scf required} = \frac{\mathsf{D} + 33}{33} \times 1.4 \times \mathsf{N} \times \mathsf{T}$$

Where:

D	=	Depth (fsw)
1.4	=	Consumption rate in acfm needed per diver from Table 8-2
N	=	Number of divers
T	=	Time at depth (minutes)

Bottom time: 30 minutes

$$\begin{aligned}\text{scf required} &= \frac{130 + 33}{33} \times 1.4 \times 3 \times 30 \\ &= 622.36\ \text{scf}\end{aligned}$$

Decompression stops: A dive to 130 fsw for 30 minutes requires the following decompression stops:

- 3 minutes at 20 fsw

$$\text{scf required} = \frac{20 + 33}{33} \times 1.4 \times 3 \times 3$$
$$= 20.24$$

- 18 minutes at 10 fsw

$$\text{scf required} = \frac{10 + 33}{33} \times 1.4 \times 3 \times 18$$
$$= 98.51 \text{ scf}$$

Ascent time: 5 minutes (rounded up from 4 minutes 20 seconds) from 130 fsw to the surface at 30 feet per minute.

$$\text{average depth} = \frac{130}{2} = 65 \text{ fsw}$$

$$\text{scf required} = \frac{65 + 33}{33} \times 1.4 \times 3 \times 5$$
$$= 62.36 \text{ scf}$$

$$\text{Total air required} = 622.36 + 20.24 + 98.51 + 62.36$$
$$= 803.48 \text{ scf (round to 804 scf)}$$

4. Calculate the air remaining at the completion of the dive to see if there is sufficient air in the air supply flasks to make the dive.

scf remaining = scf available – scf required
= 5609 scf – 804 scf
= 4805 scf

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. The Diving Supervisor must note initial volume/pressure and continually 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.**

8-3 MK 20 MOD 0

The MK 20 MOD 0 is a surface-supplied UBA consisting of a full face mask, diver communications components, equipment harness, and an umbilical assembly (Figure 8-2). One of its primary uses is in enclosed spaces, such as submarine ballast tanks. The MK 20 MOD 0 is authorized for use to a depth of 60 fsw with surface-supplied air and must have an Emergency Gas Supply when used for enclosed space diving.

Figure 8-2. MK 20 MOD 0 UBA.

8-3.1 **Operation and Maintenance.** Safety considerations and working procedures are covered in Chapter 6. NAVSEA SS600-AK-MMO-010 *Technical Manual, Operations and Maintenance Instruction Manual* is the technical manual for the MK 20 MOD 0. To ensure safe and reliable service, the MK 20 MOD 0 system must be maintained and repaired in accordance with PMS procedures and the MK 20 MOD 0 operation and maintenance manual.

8-3.2 **Air Supply.** Air for the MK 20 MOD 0 system is supplied from the surface by either an air compressor or a bank of high-pressure flasks as described in paragraph 8-7.2.3.

8-3.2.1 **EGS Requirements for MK 20 MOD 0 Enclosed-Space Diving.** 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 consists of:

- An adequately charged ANU approved scuba cylinder with either a K- or J-valve.
- An approved scuba regulator set at manufacturer's recommended pressure, but not lower than 135 psi, with an extended EGS whip 50 to 150 feet in length. If the diving scenario dictates leaving the EGS topside, adjust the first stage regulator to 150 psig.
- An approved submersible pressure gauge.

The scuba cylinder may be left on the surface and the EGS whip may be married to the diver's umbilical, or it may be secured at the opening of the enclosed space being entered. 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.

An adequately charged scuba cylinder is defined as the pressure that provides sufficient air to bring the diver to his first decompression stop or the surface for no-decompression dives. It is assumed that this will give topside personnel enough time to perform required emergency procedures to restore umbilical air to the diver. See paragraph 8-2.2.1 for calculating minimum cylinder pressure.

8-3.2.2 **EGS Requirements for MK 20 MOD 0 Open Water Diving.** When conducting open water dives, the diving supervisor may use a MK 20 designated ANU approved cylinder with the DSI sideblock assembly as an emergency air source.

8-3.2.3 **Flow Requirements.** The MK 20 MOD 0 requires a breathing gas flow of 1.4 acfm and an overbottom pressure of 90 psig. Flow and pressure requirement calculations are identical to those for the MK 21 MOD 1 (see paragraph 8-2.2.3).

8-4 EXO BR MS

8-4.1 **EXO BR MS.** The EXO BR MS is a commercial-off-the-self, full face mask, manufactured by Kirby Morgan Dive Systems, which can be used for either SCUBA or surface supplied diving. It is authorized for use to 190 fsw with air and 140 fsw with nitrox. An Emergency Gas Supply (EGS) is mandatory at depths deeper than 60 fsw and when diving inside an enclosed space. The Diving Supervisor may elect to use an EGS that can be man-carried or located outside the enclosed space and connected to the diver with a 50-150 foot whip. Conducting air dives below 190 fsw requires CNO approval.

8-4.2 **Operations and Maintenance.** The technical manual for the EXO BR MS is the Kirby Morgan Operations & Maintenance Manual, EXO BR MS Balanced Regulator Full Face Mask Military Standard (DSI Part #100-036). To ensure safe and reliable service, the EXO BR MS must be maintained and repaired in accordance with PMS procedures and the technical manual.

8-4.3 **Air Supply.** For surface supplied diving, air for the EXO BR MS is supplied from the surface by either an air compressor or a bank of high-pressure flasks as described in paragraph 8-7.2.3

8-4.4 **EGS Requirements for EXO BR MS.** The EGS system consists of adequately charged ANU approved cylinder with either a K- or J- valve and an approved first stage regulator set at manufacturer's recommended pressure but no lower than 135 psi over bottom pressure. The intermediate hose of the first stage is coupled to the emergency gas supply valve on the manifold block assembly. A relief valve set at 180 +/-5 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 manifold block. A submersible pressure gauge is also required on the first stage regulator.

When diving enclosed spaces during ship husbandry operations, the use of an approved second stage regulator with extended EGS whip 50 to 150 feet in length is permissible. The manifold block is not used and the diver's umbilical is connected directly to the low pressure high flow hose from the mask. The scuba cylinder may be left on the surface or secured at the opening of the enclosed space. The second stage regulator of the EGS is securely attached to the diver so diver has immediate access to the EGS regulator in an emergency. If the diving scenario dictates leaving the EGS topside, adjust the first stage regulator to 150 psig. When diving in submarine ballast tanks, the mask and umbilical may be left up inside the ballast tank adjacent to the opening with the extended EGS whip trailing the diver.

An adequately charged scuba cylinder is defined as the pressure that provides sufficient air to bring the diver to his first decompression stop or the surface for no-decompression dives. It is assumed that this will give topside personnel enough time to perform required emergency procedures to restore umbilical air to the diver. See paragraph 8-2.2.1 for calculating minimum cylinder pressure.

For UWSH or other unique open water dives 60 fsw and shallower, the diving supervisor may use an ANU approved cylinder designated for EXO BR MS as an emergency air source.

8-4.5 **Flow and Pressure Requirements.** The EXO BR MS requires a breathing gas flow of 1.4 acfm. For dives shallower than 130 fsw, the overbottom pressure shall be 135-165psi. For those systems which cannot maintain 135 psi overbottom pressure when diving shallower than 60 fsw, 90 psi is permissible. For dives 130-190 fsw, the overbottom pressure shall be 165-225psi. Flow and pressure calculations are identical to those for the MK21 MOD 1 (see paragraph 8-2.2.3).

8-5 PORTABLE SURFACE-SUPPLIED DIVING SYSTEMS

8-5.1 **MK 3 MOD 0 Lightweight Dive System (LWDS).** The MK 3 MOD 0 LWDS is a portable, self-contained, surface-supplied diver life-support system (DLSS). The MK 3 MOD 0 LWDS can be arranged in three different configurations and may be deployed pierside or from a variety of support platforms. Each LWDS includes a control console assembly, volume tank assembly, medium-pressure air compressor (optional), and stackable compressed-air rack assemblies, each consisting of three high-pressure composite flasks (0.935 cu ft floodable volume each). Each flask holds 191 scf of compressed air at 3,000 psi. The MK 3 MOD 0 LWDS provides sufficient air for two working divers and one standby diver operating at a moderately heavy work rate to a maximum depth of 60 fsw in configuration 1, 130 fsw in configuration 2, and 190 fsw in configuration 3. The MK 3 MOD 0 will support diving operations with both UBA MK 20 MOD 0 and UBA MK 21 Mod 1. Set-up and operating procedures for the LWDS are found in the Operating and Maintenance Instructions for Lightweight Dive System (LWDS) MK 3 MOD 0, SS500-HK-MMO-010.

8-5.1.1 **MK 3 MOD 0 Configuration 1.** Air is supplied by a medium-pressure diesel driven compressor unit supplying primary air to the divers at 18 standard cubic feet per minute (scfm) with secondary air being supplied by one air-rack assembly. Total available secondary air is 594 scf. See Figure 8-3.

Figure 8-3. MK 3 MOD 0 Configuration 1.

8-5.1.2 **MK 3 MOD 0 Configuration 2.** Primary air is supplied to the divers using three flask rack assemblies. Secondary air is supplied by one flask rack assembly. Total available primary air is 1782 scf at 3,000 psi. Total available secondary air is 594 scf. See Figure 8-4.

8-5.1.3 **MK 3 MOD 0 Configuration 3.** Primary air is supplied to the divers using three flask rack assemblies. Secondary air is supplied by two flask rack assemblies. Total available primary air is 1,782 scf. Total available secondary air is 1,188 scf. See Figure 8-5.

8-5.2 **MK 3 MOD 1 Lightweight Dive System.** This system is identical to the MK 3 MOD 0 LWDS except that the control console and volume tank have been modified to support 5,000 psi operations for use with the Flyaway Dive System (FADS) III. With appropriate adapters the system can still be used to support normal LWDS operations. See Figure 8-6.

8-5.3 **ROPER Diving Cart.** The ROPER diving cart 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 (Figure 8-7). The system is self-contained, transportable, and certifiable in accordance with *U.S. Navy Diving*

Figure 8-4. MK 3 MOD 0 Configuration 2.

Figure 8-5. MK 3 MOD 0 Configuration 3.

Figure 8-6. Flyaway Dive System (FADS) III.

Figure 8-7. ROPER Cart.

and Hyperbaric System Safety Certification Manual, NAVSEA SS521-AA-MAN-010. The major components/subsystems mounted within the cart body are:

- **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 cu ft, 3,000 psi air flasks; secondary air source of a single 1.52 cu ft, 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.

8-5.4 **Flyaway Dive System (FADS) I.** The FADS I 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 depending on the diving equipment in use. MK 21 MOD 1 and MK 20 equipment may be employed with the FADS I. See Figure 8-8.

Operational instructions for FADS I and II are covered in *Fly Away Diving System Filter/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.*

8-5.5 **Flyaway Dive System (FADS) II.** The FADS II is a self-supported, air transportable, 0–190 fsw air diving system, designed and packaged for rapid deployment worldwide to a vessel of opportunity (see Figure 8-9). Primarily intended for use in salvage or inspection and emergency ship repairs, the system's main components are:

- **Diving outfit**. Four demand helmet (MK 21 MOD 1) assemblies with umbilicals, communication system, tool kit, and repair parts kit.
- **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.

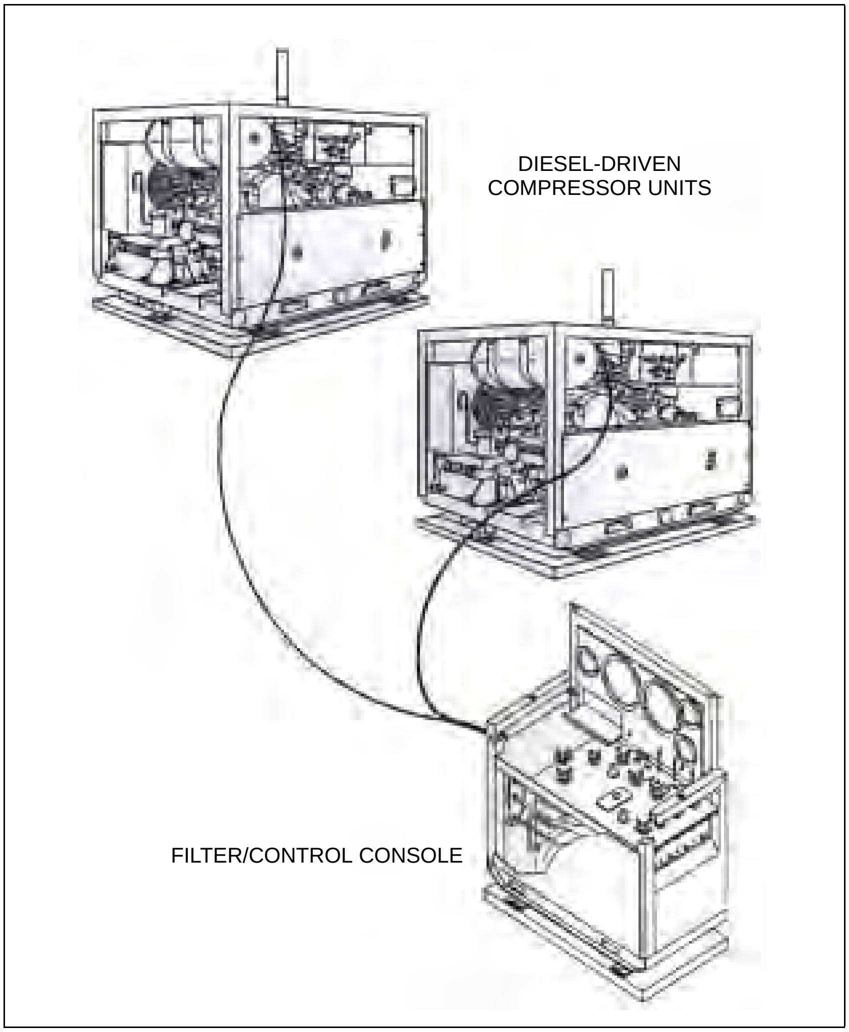


Figure 8-8. Flyaway Air Diving System (FADS) I.

- **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 secondary diver and chamber air.

- **HP oxygen tank**. 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 equipments storage.

8-5.6 Flyaway Dive System (FADS) III.

The FADS III is a portable, self-contained, surface-supplied diver life-support system designed to support dive missions to 190 fsw (Figure 8-9). Compressed air at 5,000 psi is contained in nine 3.15 cu ft floodable volume composite flasks vertically mounted in an Air Supply Rack Assembly (ASRA). The ASRA will hold 9600 scf of compressed air at 5,000 psi. Compressed air is provided by a 5,000 psi air compressor assembly which includes an air purification system. The FADS III also includes a control console assembly and a volume tank assembly. Three banks of two, three, and four flasks allow the ASRA to provide primary and secondary air to the divers as well as air to support chamber operations. Set-up and operating procedures for the FADS III are found in the *Operating and Maintenance Technical Manual for Fly Away Dive System (FADS) III Air System,* S9592-B1-MMO-010.

Figure 8-9. Air Supply Rack Assembly (ASRA) of FADS III.

8-6 ACCESSORY EQUIPMENT FOR SURFACE-SUPPLIED DIVING

Accessory equipment that is often useful in surface-supplied diving operations includes the following items:

- **Lead Line**. The lead line is used to measure depth.

- **Descent Line**. The descent line guides the diver to the bottom and is used to pass tools and equipment. A 3-inch double-braid line is recommended, 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, the stage is used to put divers into the water and to bring 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 seized with wire or with a cotter pin 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 to raise and lower the stage, the stage line is to be 3-inch double braid, or 3/8-inch wire rope minimum, taken to a capstan or run off a winch and davit.

- **Diving Ladder**. The diving ladder is used to enter the water from a vessel.

- **Weights**. Cast iron or lead weights are used to weight the descent line.

- **Tool Bag**. The tool bag is used to carry tools.

- **Stopwatches**. Stopwatches are used to time the total dive time, decompression stop time, travel time, etc.

8-7 SURFACE AIR SUPPLY SYSTEMS

The diver's air supply may originate from an air compressor, a bank of high-pressure air flasks, or a combination of both.

8-7.1 Requirements for Air Supply.

Regardless of the source, the air must meet certain established standards of purity, must be supplied in an adequate volume for breathing, and must have a rate of flow that properly ventilates 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.

8-7.1.1 **Air Purity Standards.** Air taken directly from the atmosphere and pumped to the diver 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. Refer to Table 4-1 for compressed air purity requirements.

To meet these standards, specially designed compressors must be used with the air supplied 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 satisfactorily meets the standards established above, it must be checked at intervals not to exceed 8 months, in accordance with the PMS.

8-7.1.2 **Air Supply Flow Requirements.** The required flow from an air supply depends upon the type of diving apparatus being used. The open-circuit air supply system must have a flow capacity (in acfm) that provides sufficient ventilation at depth to maintain acceptable carbon dioxide levels in the mask or helmet. Carbon dioxide levels must be kept within safe limits during 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.

8-7.1.3 **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 that is introduced as the air flows through the hoses and valves of the system. Table 8-2 shows the values for air consumption and minimum over-bottom pressures required for each of the surface-supplied air diving systems.

Table 8-2. *Primary Air System Requirements.*

System	Minimum Manifold Pressure (MMP)	Air Consumption Average Over Period of Dive (acfm)
MK 21 MOD 1	(Depth in fsw × 0.445) + 90 to 165 psi, depending on the depth of the dive	1.4 (Note 1)
MK 20 MOD 0	(Depth in fsw × 0.445) + 90 psi	1.4

Note 1: The manifold supply pressure requirement is 90 psig over-bottom pressure for depths to 60 fsw, and 135 psig over-bottom pressure for depths from 61-130 fsw. For dives from 131-190 fsw, 165 psig over-bottom pressure shall be used.

8-7.1.4 **Water Vapor Control.** 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.

8-7.1.5 **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.

8-7.2 **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 8-2). The capacity of the primary supply must 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 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.

8-7.2.1 **Requirements for Operating Procedures and Emergency Procedures.** 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 or NAVFAC approved in accordance with paragraph 4-2.6.3 Should the surface-supplied diving system be integrated with a recompression chamber, an air supply allowance for chamber requirements (Volume 5) must be made.

All valves and electrical switches that 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 is required when operating directly from a low pressure air compressor. The volume tank maintains the air supply should the primary supply source fail, providing time to actuate a secondary air supply. It also absorbs pressure pulsations resulting from the compressor operation. A volume tank may also be required when the volume tank is an integral part of the system design such as a Lightweight Dive System. When operating from a high pressure air source, a volume tank is not required if the pressure reducer has been proven to withstand significant pressure cycling caused by use of UBA demand regulators.

8-7.2.2 **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. The NAVSEA/00C ANU list contains guidance for Navy-approved compressors for divers' air systems. See Figure 8-10.

8-7.2.2.1 ***Reciprocating Air Compressors.*** Reciprocating air compressors are the only compressors authorized for use in Navy air diving operations. low pressure (LP) models can provide rates of flow sufficient to support surface-supplied air diving or recompression chamber operations. High-pressure models can charge high-pressure air banks and scuba cylinders.

8-7.2.2.2 ***Compressor Capacity Requirements.*** Air compressors must meet the flow and pressure requirements outlined in paragraph 8-7.1.2 and paragraph 8-7.1.3. Normally, reciprocating compressors have their rating (capacity in cubic feet per minute and delivery pressure in psig) stamped on the manufacturer's identification plate. This rating is usually 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 either increases or decreases from rated values. If not provided directly, capacity will be provided by conducting a compressor output test (see Topside Tech Notes, Volume II Compressors/Process Instruction NAVSEA-00C4-PI-004, Compressor Capacity Testing). Since the capacity is the volume of air at defined atmospheric conditions, compressed per unit of time, it is affected only by the first stage, as all other stages only 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 that specify the bore and stroke.

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 normally have an actual capacity of about 85 percent of their displacement. The smaller the first stage piston, the lower the percentage capacity, because the clearance volume represents a greater percentage of the cylinder volume.

8-7.2.2.3 ***Lubrication.*** Reciprocating piston compressors are either oil lubricated or water lubricated. The majority of the Navy's diving compressors are lubricated by petroleum or synthetic oil. In these compressors, the lubricant:

- Prevents wear between friction surfaces
- Seals close clearances
- Protects against corrosion
- Transfers heat away from heat-producing surfaces
- Transfers minute particles generated from normal system wear to the oil sump or oil filter if so equipped

8-7.2.2.4 ***Lubricant Specifications.*** Unfortunately, the lubricant vaporizes 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. Where the compressor manufacturer specifically recommends using a synthetic base oil, the recommended oil may be used in lieu of MIL-L-17331 or MIL-H-17672 oil.

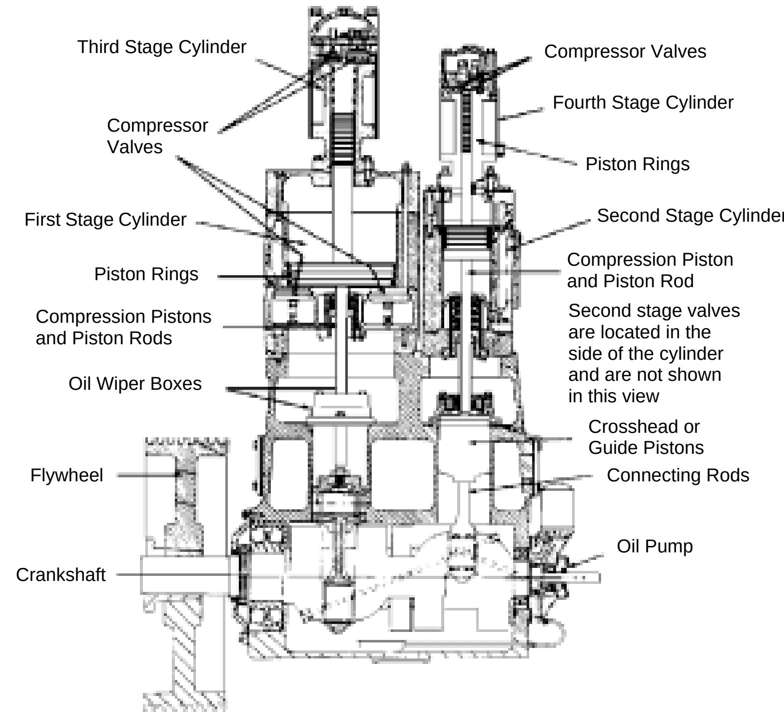
8-7.2.2.5 ***Maintaining an Oil-Lubricated Compressor.*** Using an oil-lubricated compressor for diving is contingent upon proper maintenance to limit the amount of oil introduced into the diver's air (see *Topside Tech Notes*, March 1997). When using any lubricated compressor for diving, the air must 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 air analysis must be conducted to determine whether the amount of oil present exceeds the maximum permissible level in accordance with table Table 4-1.

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 that provides excessive pressure contributes to the buildup of lubricant in the air supply.

8-7.2.2.6 ***Intercoolers.*** Intercoolers are heat exchangers that 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.

8-7.2.2.7 ***Filters.*** 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. Approved filters are listed in the NAVSEA/00C ANU list.

HP Compressor Assembly



MP Compressor Assembly

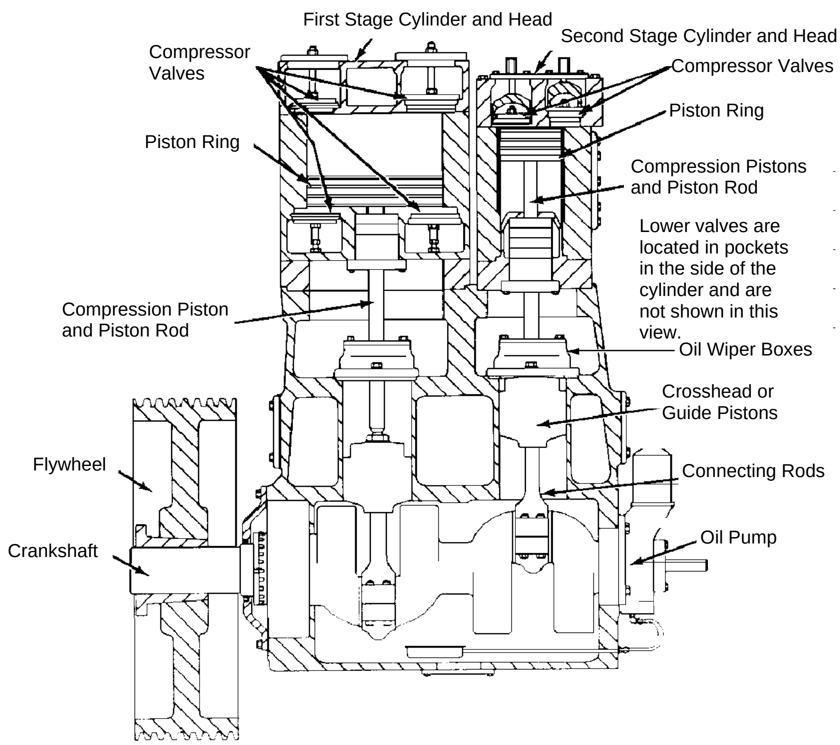


Figure 8-10. HP Compressor Assembly (top); MP Compressor Assembly (bottom).

8-7.2.2.8 ***Pressure Regulators.*** A back-pressure regulator will be installed downstream of the compressor discharge. A compressor only compresses air to meet the supply pressure demand. If no demand exists, air is simply 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 expands across the pressure regulator and enters the air banks or volume tank. As the pressure builds up in the air banks or volume tank, it eventually reaches the relief pressure of the compressor, at which time the excess air is simply 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.

8-7.2.3 **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 using 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.

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 pressure reducing valve and a volume tank (when required).

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 200 psi over minimum manifold pressure. This minimum pressure of 200 psi must remain in each flask or cylinder.

As in scuba operations, the quantity of air that 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 Sample Problem 1 in paragraph 8-2.2.3 for the MK 21 MOD 1. The sample problems in this chapter do not take the secondary air system requirements into account. The secondary air system must be able to provide 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 21 sample problem (Sample Problem 2), this would mean decompressing three divers with a 30-minute bottom time using 1.4 acfm per diver. An additional requirement must be considered if the same air system is to support a recompression chamber. Refer to Chapter 21 for information on the additional capacity required to support a recompression chamber.

8-7.2.4 **Shipboard Air Systems.** Many Navy ships have permanently installed shipboard air supply systems that 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 automatically keeps 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.

8-8 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 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.

8-8.1 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 should be 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 21 MOD 1 and the MK 20 MOD 0. This is a surface/underwater system that allows conference communications between the tender and up to three divers. It incorporates voice correction circuitry that 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.

8-8.2 **Line-Pull Signals.** A line-pull signal consists of one pull or a series of sharp, distinct pulls on the umbilical that are strong enough to be felt by the diver (Figure 8-11). All slack must be taken out of the umbilical before the signal is given.

The line-pull signal code (Table 8-3) 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 acknowledgment consists of replying with the same signal. If a signal is not properly 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 (see paragraph 6-10.8.2).

There are three line-pull signals that are not answered immediately. Two of these, from diver to tender, are "Haul me up" and "Haul me up immediately." Acknowledgment 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 that 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 using searching signals, the diver must face the line (either the lifeline or the descent line, if a circling line is being employed).

8-9 PREDIVE PROCEDURES

The predive activities for a surface-supplied diving operation involve many people and include inspecting and assembling the equipment, activating the air supply systems, and dressing the divers.

Figure 8-11. Communicating with Line-Pull Signals.

8-9.1 Predive Checklist. 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 Diver Safety and Planning Checklist (Figure 6-19) and suggested Predive Checklist (Figure 6-21).

8-9.2 Diving Station Preparation. 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 that could be damaged are placed out of the way (preferably off the deck). A standard layout pattern should be established and followed.

8-9.3 Air Supply Preparation. The primary and secondary air supply systems are checked to ensure that adequate air is available. 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. 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 (see paragraph 8-7.1.1

8-9.4 Line Preparation. Depth soundings are taken and descent line, stage, stage lines, and connections are checked, with decompression stops properly marked.

8-9.5 Recompression Chamber Inspection and Preparation. If available, the recompression chamber is inspected and all necessary equipment and a copy of appropriate recompression treatment tables are placed on hand at 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 Chapter 21.

Table 8-3. *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, two 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 all right.” When descending, one pull means “Stop” or “I am on the bottom.”	7 Pulls	“Go on (or off) searching signals.”
2 Pulls	“Lower” or “Give me slack.”	1 Pull	“Stop and search where you are.”
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 SHALL BE ANSWERED AS GIVEN EXCEPT 4-4-4			

8-9.6 **Predive Inspection.** 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.

8-9.7 **Donning Gear.** Dressing the divers is the responsibility of the tender.

8-9.8 **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. Chapter 6 contains typical predive checklists for surface-supplied equipment. Refer to the appropriate operations and maintenance manual for detailed checklists for specific equipment.

8-10 WATER ENTRY AND DESCENT

Once the predive procedures have been completed, the divers are ready to enter the water. There are several ways to enter the water, with the choice usually determined by the nature of the diving platform. Regardless of the method of entry, the divers should look before entering the water. Three methods for entering the water are the:

- Ladder method
- Stage method
- Step-in method

8-10.1 **Predescent Surface Check.** In the water and prior to descending to operating depth, the diver makes a final equipment check.

- 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 at this time.

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.

8-10.2 **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 or she 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 guidelines for descent are as follows:

- With a descent line, the diver locks the legs around the line and holds on to the line with one hand.

- 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.

- 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.

- The maximum allowable rate of descent, by any method, shall not exceed 75 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.

- The diver signals arrival on the bottom and quickly checks bottom conditions. Conditions that 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.

- A diver should thoroughly ventilate 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 or her divers' ventilation.

8-11 UNDERWATER PROCEDURES

8-11.1 Adapting to Underwater Conditions. Through careful and thorough planning, the divers can be properly prepared for the underwater conditions at the diving site. The diver will employ the following techniques to adapt to underwater conditions:

- 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 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. However, bottom current may differ from the surface current. The direction of current flow may change significantly during the period of the dive. If the diver has any trouble in orientation, the tender can guide the diver by using the line-pull searching signals.

The diver is now ready to move to the work site and begin the assignment.

8-11.2 Movement on the Bottom. Divers should follow these guidelines for movement on the bottom areas:

- Before leaving the descent line or stage, ensure that the umbilical is not fouled.

- Loop one turn of the lifeline and air hose over an arm; this acts as a buffer against a sudden surge or pull on the lines.

- Proceed slowly and cautiously to increase safety and to conserve energy.

- If obstructions are encountered, adjust buoyancy to pass over the obstruction (not under or around). If you pass around an obstruction, you must return by the same side to avoid fouling lines.

- When using buoyancy adjustments to aid in movement, avoid bouncing along the bottom; all diver movements are controlled.
- If the current is strong, stoop or crawl to reduce body area exposed to the current. Adjust the inflation of the dress to compensate for any change in depth, even if the change is only a few feet.
- When moving on a rocky or coral bottom, make sure lines do not become fouled on outcroppings, guarding against tripping and getting feet caught in crevices. Watch for sharp projections that can cut hoses, diving dress or unprotected hands. The tender is particularly careful to take up any slack in the diver's umbilical to avoid fouling.
- Guard against slipping and falling on gravel bottoms, especially on slopes.
- Avoid unnecessary movements that stir up the bottom and impair visibility.

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.**

- Mud and silt may not be solid enough to support your weight. Many hours may be spent working under mud without unreasonable risk. The primary hazard with mud bottoms comes from the concealment of obstacles and dangerous debris.

8-11.3 **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 are:

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 marking 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 (Jack-Stay) 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. These buoys may be readjusted to enlarge search areas.

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.

8-11.4 **Enclosed Space Diving.** Divers are often required to work in an enclosed or confined space. Enclosed space diving shall be supported by a surface-supplied air system (MK 20 MOD 0, MK 21 MOD 1, and EXO BR MS).

8-11.4.1 **Enclosed Space Hazards.** The interior of sunken ships, barges, submarine ballast tanks, mud tanks, sonar domes, and cofferdams is hazardous due to limited access, poor visibility, and slippery surfaces. Enclosed spaces may be dry or flooded, and dry spaces may contain a contaminated atmosphere.

NOTE **When a diver is working in an enclosed or confined space with the exception of submarine ballast tanks, the Diving Supervisor shall have the diver tended by another diver at the access opening. Ultimately, the number of tending divers deployed depends on the situation and the good judgement of the Diving Officer, Master Diver, or Diving Supervisor on the site.**

8-11.4.2 **Enclosed Space Safety Precautions.** Because of the hazards involved in enclosed space operations, divers must rigorously adhere to the following warnings.

WARNING **During enclosed space diving, all divers shall be outfitted with a MK 21 MOD 1, MK 20 MOD 0, or EXO BR MS that includes a diver-to-diver and diver-to-topside communications system and an EGS for the diver inside the space.**

WARNING **For submarine ballast tanks, 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 Chapter 4, or the submarine L.P. blower, and tests confirm that the atmosphere is safe for breathing. Tests of the air in the enclosed space shall be conducted hourly. Testing shall be done in accordance with NSTM 074, Volume 3, Gas Free Engineering (S9086-CH-STM-030/CH-074) for forces afloat, and NAVSEA S-6470-AA-SAF-010 for shore-based facilities. If the divers smell any unusual odors they shall immediately don their EGS.**

WARNING **If the diving equipment should fail, the diver shall immediately switch to the EGS and abort the dive.**

8-11.5 **Working Around Corners.** When working around corners where the umbilical is likely to become fouled or line-pull signals may be dissipated, a second diver (tending diver) may be 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.

8-11.6 **Working Inside a Wreck.** 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 judgment of the Diving Officer, Master Diver, or 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 21 MOD 1 and MK 20 MOD 0 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.

8-11.7 **Working With or Near Lines or Moorings.** When working with or near lines or moorings, observe the following rules:

- Stay away from lines under strain.
- Avoid passing under lines or moorings if at all possible; avoid brushing against lines or moorings that have become encrusted with barnacles.
- 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.
- 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).
- Never cut a line unless the line is positively identified.
- 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, make sure the diver is clear of the lift area or leaves the water.

8-11.8 **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 that all umbilicals and lines are clear for ascent.
3. Assess and report your condition (level of fatigue, remaining strength, physical aches or pains, etc.) and mental acuity.

8-11.9 **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 *Underwater Ship Husbandry Manual*, S0600-AA-PRO-010, presents guidance for most commonly encountered jobs, such as replacement and repair of propellers, propeller blades, auxiliary propulsion motors, and sonar domes.

8-11.9.1 **Underwater Ship Husbandry Procedures.** Due to the complexity of ships' underwater systems and the sophistication of newly developed repair techniques, specific procedures were developed to provide guidance in the underwater repair and maintenance of U.S. Navy ships. These procedures are located in individually bound chapters of the Underwater Ship Husbandry Manual (S0600-AA-PRO-010). Chapter 1 of the manual is the Index and User Guide, which provides information on the subsequent chapters of the manual.

8-11.9.2 **Working with Tools.** Underwater work requires appropriate tools and materials, such as cement, foam plastic, and patching compounds. Many of these are standard hand tools (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 that 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. Prior to ascent or descent, secure power to all tools. 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 that transmits a force back through the diver.
- Tying a hogging line to the work also gives the diver leverage while keeping him close to his task without continually having to fight a current.

8-11.10 **Safety Procedures.** 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 6. In all situations, the Diving Supervisor should ensure that common sense and good seamanship prevail to safely resolve each emergency.

Emergency procedures are covered specifically for each equipment in its appropriate operations and maintenance manual and in general in Chapter 6. However, there are a number of situations 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.

8-11.10.1 **Fouled Umbilical 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 umbilical.

8-11.10.2 **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.

WARNING If job conditions call for using a steel cable or a chain as a descent line, the Diving Officer must approve such use.

8-11.10.3 **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.

8-11.10.4 **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 does not directly endanger breathing.

8-11.11 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 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 or waters edge, always keeping a hand on the umbilical.

3. The primary tender and a backup tender as required are always on station to assist the diver. As the diver enters the water, the tenders handle the umbilical, 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 paragraph 6-10.8.2 for loss-of-communication procedures).

8-11.12 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.

- **Supervisor Actions**.

  1. Follow the bubble trail, while considering current(s). 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.

  2. 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.

- **Tender Actions**. Feel the pull of the umbilical.

- **Additional Personnel Actions**. 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.

8-12 ASCENT PROCEDURES

Follow these ascent procedures when it is time for the divers to return to the surface:

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 pneumofathometer 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. The diver, however, does not pull up. 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, while using a descent line, the diver becomes too buoyant and rises too quickly, the diver checks the ascent by clamping his legs on the descent line.

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. 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. Refer to Chapter 9 for decompression procedures, including an explanation of the tables.

6. 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, or numbness, 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.

7. Upon arrival at the surface, topside personnel, timing the movement as dictated by any surface wave action, coordinate bringing the stage and umbilical up and over the side.

8. 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.

8-13 SURFACE DECOMPRESSION

8-13.1 Disadvantages of In-Water 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 accomplished in a recompression chamber on the support ship (Figure 8-12). Refer to Chapter 9 for surface decompression procedures.

Figure 8-12. Surface Decompression.

8-13.2 Transferring a Diver to the Chamber. When transferring a diver from the water to the chamber, the tenders are allowed no more than 3½ minutes to undress the diver. 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.

8-14 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.

8-14.1 **Personnel and Reporting.** Immediate postdive activities include any required medical treatment for the diver and the recording of mandatory reports.

- 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 2 hours after surfacing.

- Mandatory records and reports are covered in Chapter 5. Certain information is logged as soon as the diving operations are completed, while other record keeping is scheduled when convenient. The Diving Supervisor 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.

8-14.2 **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.

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CHAPTER 9

Air Decompression

9-1 INTRODUCTION

9-1.1 Purpose. This chapter discusses decompression requirements for air diving operations.

9-1.2 Scope. This chapter discusses six different tables, each with its own unique application in air diving. Four tables provide specific decompression schedules for use under various operational conditions. The fifth table is used to determine decompression requirements when a diver will dive more than once during a 12-hour period. The sixth is the Diving at High Altitudes depth correction table.

9-2 THEORY OF DECOMPRESSION

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 are higher than the partial pressure of the gas absorbed in the tissues. Nitrogen absorption increases as the partial pressure of the inspired nitrogen increases, such as with increased depth. Nitrogen absorption also increases as the duration of the exposure increases, until tissues become saturated.

As a diver ascends, the process is reversed. The partial pressure of nitrogen in the tissues comes to exceed that in the circulatory and respiratory systems. During ascent, the nitrogen diffuses from the tissues to the lungs. The rate of ascent must be carefully controlled to prevent the nitrogen pressure from exceeding the ambient pressure by too great of an amount. 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 schedules take into consideration the amount of nitrogen absorbed by the body at various depths and times. Other considerations are the allowable pressure gradients that 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. Staged 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, the tables tend to be less accurate as dive depth and time increase. 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) with the Commanding Officer’s approval.

9-3 AIR DECOMPRESSION DEFINITIONS

The following terms are frequently used when conducting diving operations and discussing the decompression tables.

9-3.1 **Descent Time.** *Descent time* is the total elapsed time from when the divers leave the surface to the time they reach the bottom. Descent time is rounded up to the next whole minute.

9-3.2 **Bottom Time.** *Bottom time* is the total elapsed time from when the divers leave the surface to the time they begin their ascent from the bottom. Bottom time is measured in minutes and is rounded up to the next whole minute.

9-3.3 **Decompression Table.** A *decompression table* is a structured set of decompression schedules, or limits, usually organized in order of increasing bottom times and depths.

9-3.4 **Decompression Schedule.** A *decompression schedule* is 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.

9-3.5 **Decompression Stop.** A *decompression stop* is a specified depth where a diver must remain for a specified length of time (stop time).

9-3.6 **Depth.** The following terms are used to indicate the depth of a dive:

- *Maximum depth* is the deepest depth attained by the diver plus the pneumofathometer correction factor (Table 9-1). When conducting scuba operations, maximum depth is the deepest depth gauge reading.

- *Stage depth* is 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 9-1. *Pneumofathometer Correction Factors.*

Pneumofathometer Depth	**Correction Factor**
0-100 fsw	+1 fsw
101-200	+2 fsw
201-300	+4 fsw
301-400	+7 fsw

9-3.7 **Equivalent Single Dive Bottom Time.** The *equivalent single dive bottom time* is the time used to select a schedule for a single repetitive dive. This time is expressed in minutes.

9-3.8 **Unlimited/No-Decompression (No "D") Limit.** The maximum time that can be spent at a given depth that safe ascent can be made directly to the surface at a prescribed travel rate with no decompression stops is the *unlimited/no-decompression* or *No "D" limit* (Table 9-7).

9-3.9 **Repetitive Dive.** A *repetitive dive is* any dive conducted within 12 hours of a previous dive.

9-3.10 **Repetitive Group Designation.** The *repetitive group designation* is a letter used to indicate the amount of residual nitrogen remaining in a diver's body following a previous dive.

9-3.11 **Residual Nitrogen.** *Residual nitrogen* is the nitrogen gas still dissolved in a diver's tissues after surfacing.

9-3.12 **Residual Nitrogen Time.** *Residual nitrogen time* is the time that 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. Residual nitrogen time is expressed in minutes.

9-3.13 **Single Dive.** A *single dive* refers to any dive conducted more than 12 hours after a previous dive.

9-3.14 **Single Repetitive Dive.** A *single repetitive dive is* 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.

9-3.15 **Surface Interval.** The *surface interval is* the time 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.

9-4 DIVE RECORDING

Chapter 5 provides information for maintaining a Command Diving Log and personal diving log and 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 9-1. The diving chart is a convenient means of collecting the dive data, which in turn will be transcribed in the dive log. Diving Record abbreviations that may be used in the Command Diving Log are:

- LS - Left Surface
- RB - Reached Bottom
- LB - Left Bottom

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
					L	
		10			R	
					L	
		20			R	
					L	
		30			R	
					L	
		40			R	
					L	
		50			R	
					L	
		60			R	
					L	
		70			R	
					L	
		80			R	
					L	
		90			R	
					L	
		100			R	
					L	
		110			R	
					L	
		120			R	
					L	
		130			R	

PURPOSE OF DIVE	REMARKS
DIVER'S CONDITION	DIVING SUPERVISOR

Figure 9-1. Air Diving Chart.

- R - Reached a stop
- L - Left a stop
- 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 9-2 illustrates these abbreviations in conjunction with a dive profile.

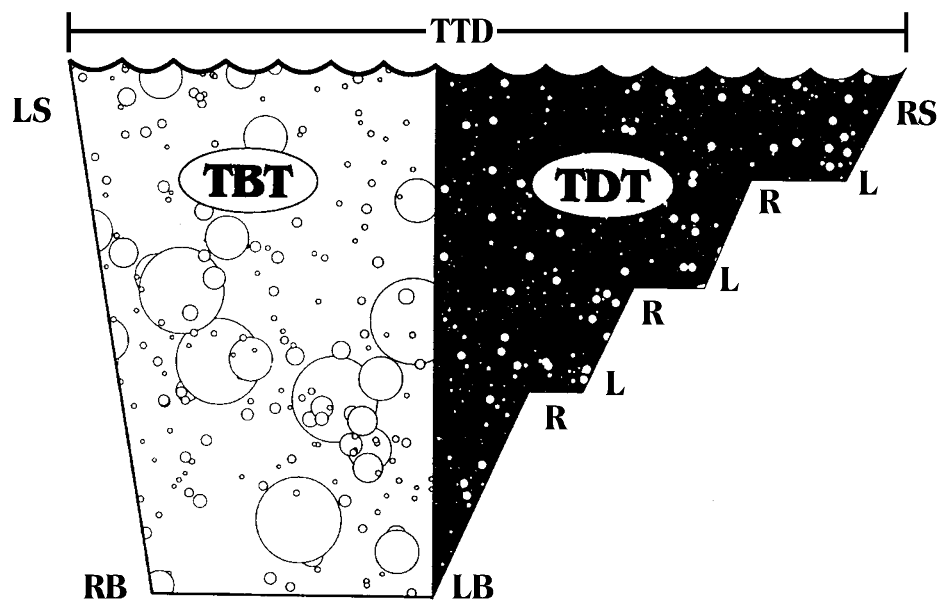


Figure 9-2. Graphic View of a Dive with Abbreviations.

9-5 TABLE SELECTION

9-5.1 Decompression Tables Available. The decompression tables available for U.S. Navy air diving operations are:

- Unlimited/No-Decompression Limits and Repetitive Group Designation Table for Unlimited/No-Decompression Air Dives
- Standard Air Decompression Table

- Surface Decompression Table Using Oxygen
- Surface Decompression Table Using Air
- Residual Nitrogen Timetables for Repetitive Air Diving
- Sea Level Equivalent Depth Table

These tables contain a series of decompression schedules or depth corrections that must be rigidly followed during an ascent from an air dive. Each table has specific conditions that justify its selection. These conditions are: depth and duration of the dive, altitude, 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 six air diving tables and the criteria for the selection and application of each are listed in Table 9-2. General instructions for using the tables and special instructions applicable to each table are discussed in paragraphs 9-6 and 9-7, respectively.

NOTE **Omitted decompression is a dangerous situation. Procedures for management of asymptomatic omitted decompression are discussed in paragraph 9-6.3.**

9-5.2 **Selection of Decompression Schedule.** The decompression schedules of all the tables are usually given in 10-foot depth increments and 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 and 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.**

When planning for surface-supplied dives where the diver will be exceptionally cold or the work load is expected to be relatively strenuous, Surface Decompression should be considered. In such case, conduct decompression from the normal schedule in the water and then surface decompress using the chamber stop time(s) from the next longer schedule. When conducting dives using Standard Air Decompression Tables, select the next longer decompression schedule than the one that would normally be selected.

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.

Table 9-2. Air Decompression Tables Selection Criteria.

U.S. Navy Standard Air Decompression Table	In-water decompression using normal and exceptional exposure dive schedules. Repetitive dives; normal decompression schedules only.
Unlimited/No-Decompression Limits and Repetitive Group Designation Table for Unlimited/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	Recompression chamber with oxygen breathing system is used for shorting of in-water decompression. Repetitive dives combine to single dive.
Surface Decompression Table Using Air	Recompression chamber without an oxygen breathing system is used for shorting of in-water decompression. Repetitive dives combine to single dive.
Sea Level Equivalent Depth Table	Altitude correction for use with tables listed above.

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. This procedure is used because the divers are generating heat and on-gassing at a normal rate while working at depth. Once decompression starts, however, the divers are at rest and begin to chill. Vasoconstriction of the blood vessels takes place and they do not off-gas at the normal rate. The additional decompression time increases the likelihood that the divers receive adequate decompression.

NOTE Take into consideration the physical condition of the diver when determining what is strenuous.

If the diver's depth cannot be maintained at a decompression stop, the Diving Supervisor may select the next deeper decompression schedule.

9-6 ASCENT PROCEDURES

9-6.1 Rules During Ascent.

9-6.1 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 or OIC concurs, decompression must be completed according to the schedule selected.

9-6.1.1 **Ascent Rate.** Always ascend at a rate of 30 fpm (20 seconds 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 9-6.2. However, a delay of up to one minute in reaching the first decompression stop can be ignored.

9-6.1.2 **Decompression Stop Time.** 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.

9-6.2 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.)

9-6.2.1 **Delays in Arriving at the First Stop.**

- **Delay greater than 1 minute, 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 113 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 fsw. During ascent, the divers were delayed at 100 fsw for: 03::27 and it actually took 6 minutes 13 seconds to reach the 30-foot decompression stop. Determine the new decompression schedule.

  Solution: If the divers had maintained an ascent rate of 30 fpm, it would have taken the divers 2 minutes 46 seconds to ascend from 113 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 9-3.

- **Delay greater than 1 minute, shallower than 50 fsw**. If the rate of ascent is less than 30 fpm, add the delay time to the diver's first decompression stop. If the delay is between stops, disregard the delay. The delay time is rounded up to the next whole minute.

  Example: A dive was made to 113 fsw 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 fsw and it actually took 6 minutes 20 seconds to reach the 30-foot stop. Determine the new decompression schedule.

  Solution: If the divers had maintained an ascent rate of 30 fpm, the correct ascent time should have been 2 minutes 46 seconds. Because it took 6 minutes 20 seconds to reach the 30-foot stop, there was a delay of 3 minutes 34 seconds (6 minutes 20 seconds minus 2 minutes 46 seconds). Therefore, increase the length of the 30-foot decompression stop by 3 minutes 34 seconds, rounded up to 4 minutes. Instead of 2 minutes, the divers must spend 6 minutes at 30 fsw. This dive is illustrated in Figure 9-4.

DIVING CHART - AIR (1537)

Date	26 June 96

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
MMCM (MDV) Curtis	MK 21	Swim	2900
NAME OF DIVER 2	**DIVING APPARATUS**	**TYPE DRESS**	**EGS (PSIG)**
HTCS (MDV) Ervin	MK 21	Swim	2900

TENDERS (DIVER 1)	TENDERS (DIVER 2)
LCDR Martinez AND CDR Orr	BMC Leet AND HTC Patterson

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
1302	113 + 2 = 115 (circled)	~~1304~~	:02
LEFT BOTTOM (LB)	**TOTAL BOTTOM TIME (TBT)**	**TABLE & SCHEDULE USED**	**TIME TO FIRST STOP**
1402	:60 (circled) + :04 = :64	Std Air 120/~~:60~~ :70	:02::20
REACHED SURFACE (RS)	**TOTAL DECOMPRESSION TIME (TDT)**	**TOTAL TIME OF DIVE (TTD)**	**REPETITIVE GROUP**
1536::13	01:34::13	02:34::13	O

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER		TIME WATER	TIME CHAMBER
	::20	10	:55 ~~:45~~		L	1535::53	
					R	1440::53	
	::20	20	:23 ~~:22~~		L	1440::33	
					R	1417::33	
	::20	30	:09 ~~:02~~		L	1417::13	
					R	1408::13	
	2::20	40			L		
					R		
		50			L		
					R		
75	30	60			L		
					R		
fpm	fpm	70			L		
					R		
		80			L		
					R		
		90			L		
					R		
		100 (circled)	Fouled 03::27		L	1405::53	
					R	1402::26	
	::26	110			L		
					R		
:02		113 ~~120~~			L	1402	
					R	~~1304~~	
		130			L		
					R		

PURPOSE OF DIVE	REMARKS
Training	Divers fouled at 100 fsw for 03::37. Rounded up to :04 add to bottom time.
DIVER'S CONDITION	**DIVING SUPERVISOR**
OK	BMCM (MDV) Burgess

Figure 9-3. Completed Air Diving Chart.

DIVING CHART - AIR

1721 (circled)

Date: 26 June 96

NAME OF DIVER 1: HTCM (MDV) Wiggins	DIVING APPARATUS: MK 21	TYPE DRESS: Swim	EGS (PSIG): 2900
NAME OF DIVER 2: CAPT. Fleischman	DIVING APPARATUS: MK 21	TYPE DRESS: Swim	EGS (PSIG): 2900
TENDERS (DIVER 1): BMC Poulan AND BM2 Christensen		TENDERS (DIVER 2): QM1 Wittman AND EN1 Credle	
LEFT SURFACE (LS): 1500	DEPTH (fsw): 113 + 2 = 115 (circled)	REACHED BOTTOM (RB): ~~1502~~	DESCENT TIME: :02
LEFT BOTTOM (LB): 1600	TOTAL BOTTOM TIME (TBT): :60	TABLE & SCHEDULE USED: 120/:60 Std Air	TIME TO FIRST STOP: :02::46
REACHED SURFACE (RS): 1720::20	TOTAL DECOMPRESSION TIME (TDT): 01:20::20	TOTAL TIME OF DIVE (TTD): 02:20::20	REPETITIVE GROUP: O

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::20	10	:45		L 1720::00 R 1635::00	
	::20	20	:22		L 1634::40 R 1612::40	
	::20	30	:02 + :04 :06		L 1612::20 R 1606::20	
	::20	40 (circled)	Fouled 03::34		L 1606::00 R 1602::26	
	2::26	50			L R	
75	30	60			L R	
f	f	70			L R	
p m	p m	80			L R	
		90			L R	
		100			L R	
		110			L R	
:02		113 ~~120~~			L 1600 R ~~1502~~	
		130			L R	

PURPOSE OF DIVE: ReQual	REMARKS: Delay shallower than 50 fsw for 03::34. Rounded up to :04 add to first stop time.
DIVER'S CONDITION: OK	DIVING SUPERVISOR: BMCM (MDV) Orns

Figure 9-4. Completed Air Diving Chart.

9-6.2.2 **Travel Rate Exceeded.** 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. If the stop is arrived at early, start the stop time after the watches catch up.

9-6.3 **ASYMPTOMATIC OMITTED DECOMPRESSION.** Certain emergencies, such as uncontrolled ascents, an exhausted air supply, or bodily injury, may interrupt or prevent required decompression. 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 addressed in some manner to avert later difficulty. Table 9-3 summarizes management of asymptomatic Omitted Decompression.

Table 9-3. *Management of Asymptomatic Omitted Decompression.*

Depth at Which Omission Began	Decompression Status	Eligible for Sur-D?	Surface Interval (Note 4)	Action Chamber Available (Note 3)	 No Chamber Available
20 fsw or shallower	No Decompression	N/A	N/A	Observe on surface for 1 hour.	
	Decompression Stops Required	Yes	Less than 5 minutes	Use Surface Decompression Tables.	Perform Chamber stops in water. (Note 1)
		No	Less than 1 minute	Return to depth of stop. Increase stop time 1 minute. Resume decompression.	
		No.	Greater than 1 minute.	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 minutes. ***OR:*** Treatment Table 6 (2A) for surface interval greater than 5 minutes.	
Deeper than 20 fsw	No-Decompression	N/A	N/A	Observe on surface for 1 hour.	
	Decompression Stops Required	Yes	Less than 5 minutes.	Use Surface Decompression Tables	Perform chamber stops in water (Note 1)
	Decompression Stops Required (Less than 30 minutes missed)	No No	Less than 5 minutes. Greater than 5 minutes.	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 minutes)	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 compress to 165' and start TT6A. If oxygen is unavailable, treat on a full Treatment Table 2A.
3. Using a recompression chamber is strongly preferred over in-water recompression for returning a diver to pressure. Compress to depth as fast as possible not to exceed 100 fsw/min.
4. For surface decompression, the 5 minute surface interval starts after leaving the 30 foot stop or 30 fsw if no in-water stops are required till the diver reaches 40 fsw in the chamber.

9-6.3.1 **Planned and Unplanned Omitted Decompression.** Omitted decompression may or may not be planned. Planned omitted decompression results when a condition develops at depth that 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 that permit using the Surface Decompression Tables are not fulfilled, the diver's decompression will be compromised. Special care shall be taken to detect signs of decompression sickness. The diver must be returned to pressure as soon as possible.

9-6.3.2 **Treating Omitted Decompression with Symptoms.** If the diver develops symptoms of decompression sickness during the surface interval, treat in accordance with the procedures in paragraph 20-3.6.2. If the diver has no symptoms of decompression sickness or arterial gas embolism, make up the omitted decompression as described in this section.

9-6.3.3 **Treating Omitted Decompression in Specific Operational Environments.** Refer to Chapter 17 or 18 as appropriate for procedures for dealing with omitted decompression during MK 16 diving operations. Refer to paragraph 14-4.10 for procedures for dealing with omitted decompression during surface-supplied helium-oxygen diving operations.

9-6.3.4 **Ascent from 20 Feet or Shallower (Shallow Surfacing) with Decompression Stops Required .** If the diver surfaced from 20 feet or shallower feels well, and can be returned to stop depth within 1 minute, the diver may complete normal decompression stops. The decompression stop from which ascent occurred is lengthened by 1 minute. If the diver cannot be returned to the depth of the stop within 1 minute and the diver remains asymptomatic, return the diver to the stop from which the diver ascended. Multiply each decompression stop time missed by 1.5. Alternatively, if the surface interval is less than 5 minutes, the diver may be placed in a recompression chamber and treated on a Treatment Table 5 (or Air Treatment Table 1A if no oxygen is available). If the surface interval is greater than 5 minutes, the diver may be placed in a recompression chamber and treated on Treatment Table 6. The diver should be observed for 1 hour after surfacing and/or completing treatment.

9-6.3.5 **Ascent from 20 Feet or Shallower with No Decompression Stops Required.** 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 1 hour.

9-6.3.6 **Ascent from Deeper than 20 Feet (Uncontrolled Ascent).** Any unexpected surfacing of the diver from depths in excess of 20 feet is considered an uncontrolled ascent. If the diver is within no-decompression limits and asymptomatic, he should be observed for at least 1 hour on the surface. Recompression is not necessary unless symptoms develop.

9-6.3.7 **Asymptomatic Uncontrolled Ascent.** Asymptomatic divers who experience an uncontrolled ascent and who have missed decompression stops are treated by recompression based on the amount of decompression missed as follows:

a. **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) were missed, decompress from 60 feet on Treatment Table 5. If more than 30 minutes of decompression were missed, decompress from 60 feet on Treatment Table 6. If an asymptomatic diver who has an uncontrolled ascent from a decompression dive has more than a 5-minute surface interval, recompress to 60 feet on Treatment Table 6, even if the missed decompression time was less than 30 minutes.

b. **Oxygen Not Available.** Compress the diver to 100 feet in the recompression chamber and treat on Air Treatment Table 1A if less than 30 minutes of decompression were missed; compress to 165 feet and treat on Air Treatment Table 2A if more than 30 minutes were missed.

9-6.3.8 **Development of Symptoms.** As long as the diver shows no ill effects, decompress in accordance with the treatment table. Consider any decompression sickness that develops during or after this procedure to be a recurrence. Try to keep all surface intervals as short as possible (5 minutes or less). In-Water Procedure.

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 5-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 1 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.

9-7 UNLIMITED/NO-DECOMPRESSION LIMITS AND REPETITIVE GROUP DESIGNATION TABLE FOR UNLIMITED/NO-DECOMPRESSION AIR DIVES

The Unlimited/No-Decompression Table (Table 9-7) serves three purposes. First, the table identifies that on a dive with the depth 20 fsw and shallower, unlimited bottom time may be achieved. Second, it summarizes all the depth and bottom time combinations for which no decompression is required. Third, it provides the repetitive group designation for each unlimited/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. Any dive deeper than 25 fsw that 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.

Each depth listed in the Unlimited/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.

To find the repetitive group designation:

1. Enter the table at the depth equal to, or next greater than, the maximum depth of the dive.
2. Follow that row to the right to the bottom time equal to, or just greater than, the actual bottom time of the dive.
3. Follow the column up to the repetitive group designation.

9-7.1 **Example.** In planning a dive, the Dive Supervisor wants the divers to conduct a brief inspection of the work site, located at a depth of 152 fsw. Determine the maximum no-decompression limit and repetitive group designation.

9-7.2 **Solution.** The maximum bottom time that may be used without requiring decompression and the repetitive group designation after the dive can be found in either the Unlimited/No-Decompression Table or the Standard Air Decompression Table.

- **Using the Unlimited/No-Decompression Table**.

  1. Locate the dive depth in the Depth column. Because there is no entry for 154 (152 +2) fsw, round the depth up to the next greater depth of 160 fsw.
  2. Move vertically across the table to locate the no-decompression limit in the Unlimited/No-Decompression Limits column. The no-decompression

limit is 5 minutes. To avoid having to make decompression stops, the divers must descend to 152 fsw, make the inspection and begin ascent within 5 minutes of leaving the surface.

3. To find the repetitive group designation, 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.

- **Using the Standard Air Decompression Table**.

1. Locate the schedule for the dive depth. Because there is no schedule for 154 (152 +2) fsw, round the depth up to the next greater depth of 160 fsw.

2. Follow the 5-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 9-5 is a diving chart for this dive.

9-8 U.S. NAVY STANDARD AIR DECOMPRESSION TABLE

This manual combines the Standard Air Decompression Schedules and Exceptional Exposure Air Schedules into one table (see Table 9-9). To clearly distinguish between the standard (normal) and exceptional exposure decompression schedules, the exceptional exposure schedules have been separated by a bold line.

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 Unlimited/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.

9-8.1 **Example.** Divers complete a salvage dive to a depth of 140 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.

9-8.2 **Solution.** Select the equal or next deeper depth and the equal or next longer bottom time (140 + 2 = 142 fsw). This would be the 150/40 schedule, repetitive group designator N (see Figure 9-6).

DIVING CHART - AIR   0811   Date 22 Nov 96

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
MMCM (MDV) Mallet	MK 21	Wet Suit	2750
NAME OF DIVER 2: HMC Chabot	DIVING APPARATUS: MK 21	TYPE DRESS: Wet Suit	EGS (PSIG): 2750

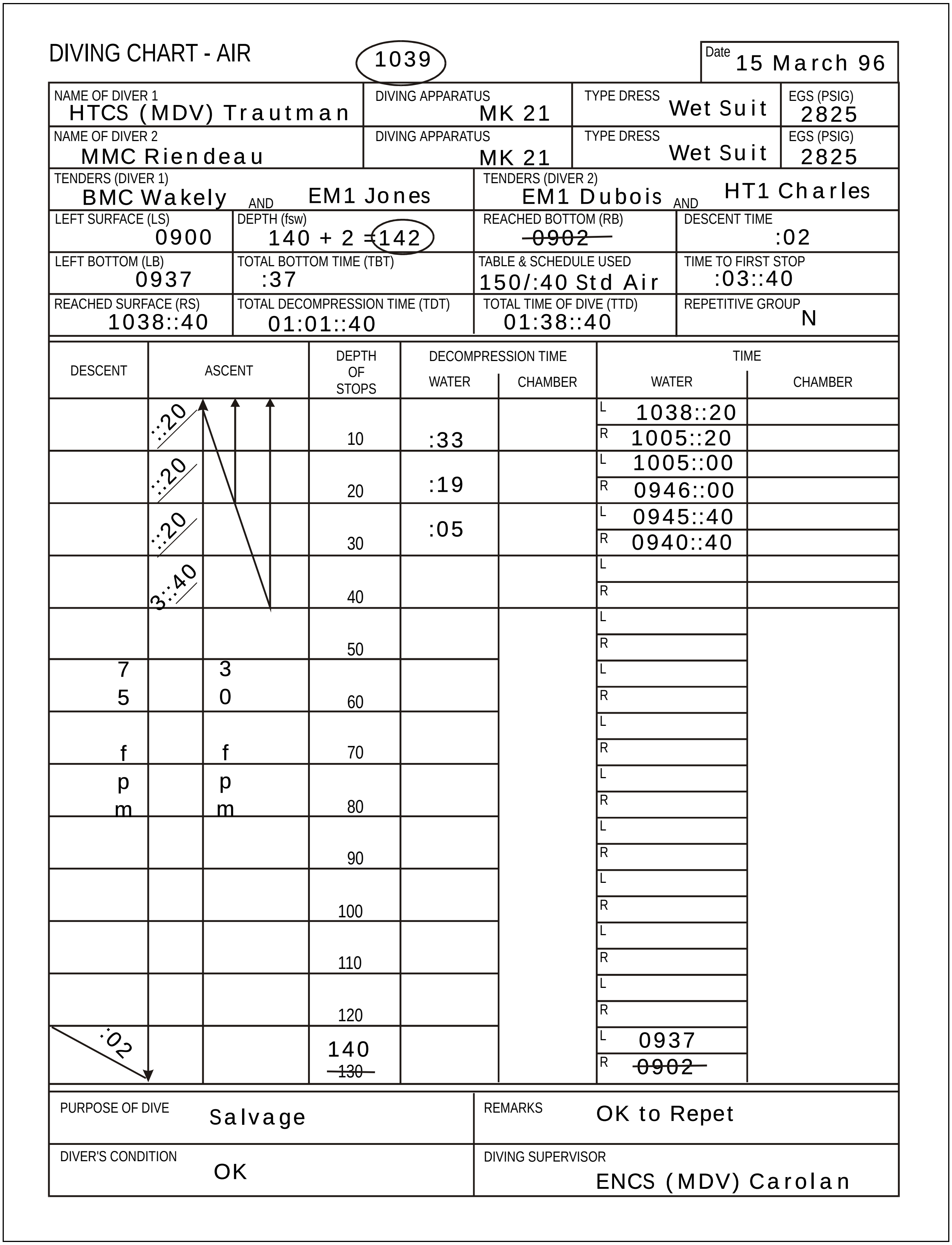
TENDERS (DIVER 1)	TENDERS (DIVER 2)
ENC Pettus AND BM1 McDaniels	HM2 Carlson AND BM2 Froelich

LEFT SURFACE (LS): 0800	DEPTH (fsw): 152 + 2 = 154	REACHED BOTTOM (RB): ~~0803~~	DESCENT TIME: :03
LEFT BOTTOM (LB): 0805	TOTAL BOTTOM TIME (TBT): :05	TABLE & SCHEDULE USED: 160/:05 No "D"	TIME TO FIRST STOP: :05::04
REACHED SURFACE (RS): 0810::04	TOTAL DECOMPRESSION TIME (TDT): 05::04	TOTAL TIME OF DIVE (TTD): 10::04	REPETITIVE GROUP: D

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	05::04	10			L R	
		20			L R	
		30			L R	
		40			L R	
		50			L R	
75	30	60			L R	
f	f	70			L R	
p m	p m	80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
:03		152 ~~130~~			L 0805 R ~~0803~~	

PURPOSE OF DIVE: Inspection Dive Site	REMARKS: OK to Repet
DIVER'S CONDITION: OK	DIVING SUPERVISOR: BMCM (MDV) Bettua

Figure 9-5. Completed Air Diving Chart.



DIVING CHART - AIR (1039)

Date 15 March 96

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
HTCS (MDV) Trautman	MK 21	Wet Suit	2825
NAME OF DIVER 2: MMC Riendeau	DIVING APPARATUS: MK 21	TYPE DRESS: Wet Suit	EGS (PSIG): 2825

TENDERS (DIVER 1): BMC Wakely AND EM1 Jones	TENDERS (DIVER 2): EM1 Dubois AND HT1 Charles

LEFT SURFACE (LS): 0900	DEPTH (fsw): 140 + 2 = 142	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::40
REACHED SURFACE (RS): 1038::40	TOTAL DECOMPRESSION TIME (TDT): 01:01::40	TOTAL TIME OF DIVE (TTD): 01:38::40	REPETITIVE GROUP: N

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::20	10	:33		L 1038::20 / R 1005::20	
	::20	20	:19		L 1005::00 / R 0946::00	
	::20	30	:05		L 0945::40 / R 0940::40	
	3::40	40			L / R	
		50			L / R	
75	30	60			L / R	
f	f	70			L / R	
p	p	80			L / R	
m	m	90			L / R	
		100			L / R	
		110			L / R	
		120			L / R	
:02		140 ~~130~~			L 0937 / R ~~0902~~	

PURPOSE OF DIVE: Salvage	REMARKS: OK to Repet
DIVER'S CONDITION: OK	DIVING SUPERVISOR: ENCS (MDV) Carolan

Figure 9-6. Completed Air Diving Chart.

9-9 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 9-7. Upon completing the first dive, the divers are assigned a repetitive group designation from either the Standard Air Decompression Table or the Unlimited/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 (Table 9-8), this designation may be determined at any time during the surface interval.

To determine the decompression schedule for a repetitive dive using either the unlimited/no-decompression, standard air, or surface decompression table:

1. Determine the residual nitrogen level just prior to leaving the surface of the of the repetitive dive (based on the repetitive dive depth), using the Residual Nitrogen Timetable. This level is expressed as residual nitrogen time, in minutes.

2. Add this time to the actual bottom time of the repetitive dive to get the Equivalent Single Dive Time (ESDT).

3. Conduct decompression from the repetitive dive using the max depth (MD) and the equivalent single dive time 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 9-8, when determining the decompression schedule for a repetitive dive.

9-9.1 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 Unlimited/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 a 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:

1. Locate the diver's repetitive group designation from the previous dive along the diagonal line above the table.

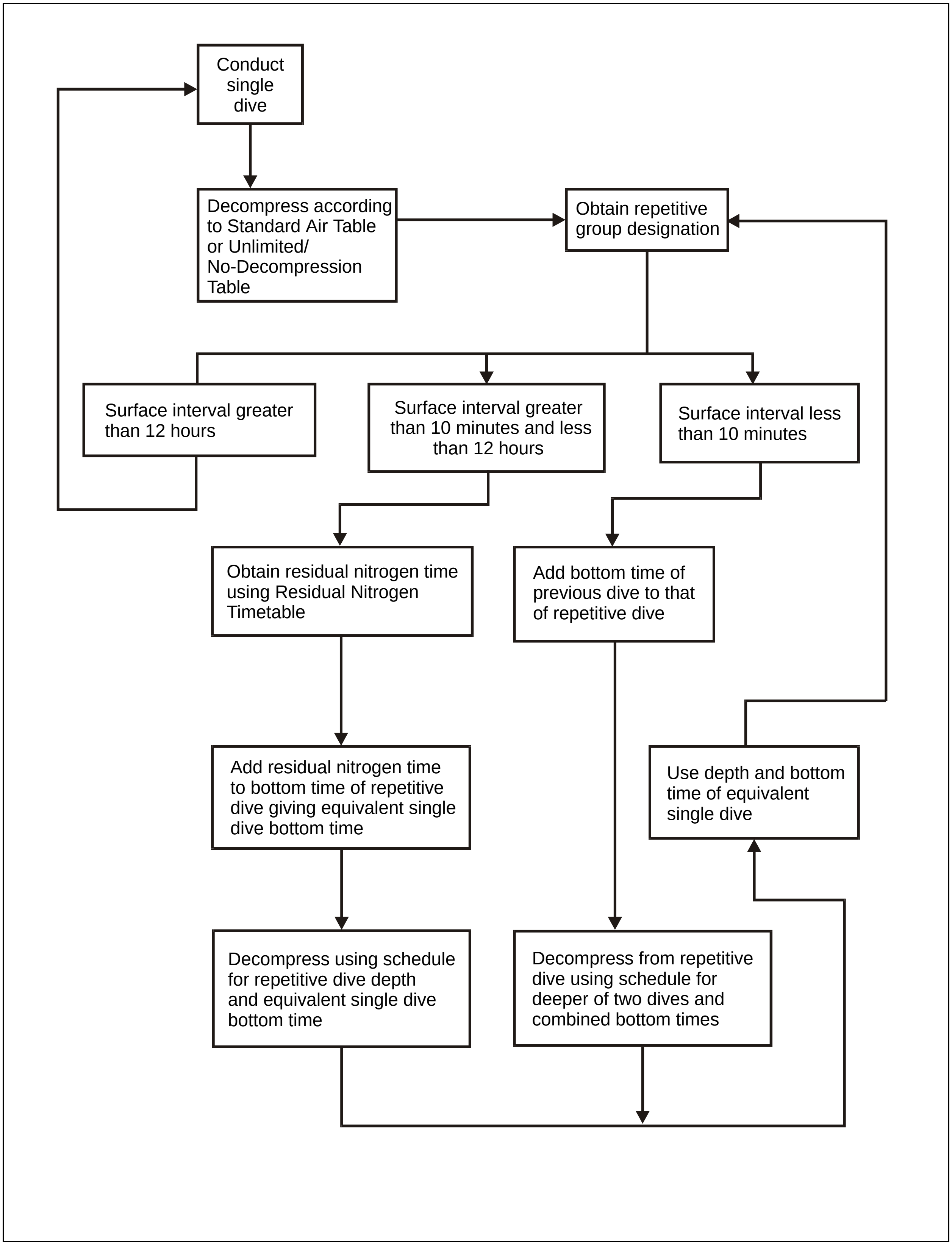


Figure 9-7. Repetitive Dive Flowchart.

REPETITIVE DIVE WORKSHEET

							Date:
1st DIVE							
Max Depth							
Bottom Time							
Table & Schedule						**REPET Group**	
Surface Interval						**New Group**	
2nd DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		**=**		**=**		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	
3rd DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		**=**		**=**		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	
4th DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		**=**		**=**		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	

Figure 9-8. Repetitive Dive Worksheet.

2. Read horizontally to the interval where the diver's surface interval lies. The time spent on the surface must be between or equal to the limits of the selected interval.

3. Read vertically down to the new repetitive group designation. This corresponds to the present quantity of residual nitrogen in the diver's body.

4. Continue down in this same column to the row representing 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.

9-9.1.1 **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 100 (100+1=101) 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.

1. Use the 110/50 schedule of the Standard Air Decompression Table to find the residual nitrogen time of the previous dive. Read across the 50-minute bottom time row to find the repetitive group designator of M.

2. Move to the Residual Nitrogen Timetable for Repetitive Air Dives.

3. Enter the table on the diagonal line at M.

4. Read horizontally across the line until reaching the surface interval coinciding with the diver's surface interval of 6 hours 26 minutes. The diver's surface interval falls within the limits of the 6:19/9:28 column.

5. Read vertically down the 6:19/9:28 column until reaching the depth coinciding with the repetitive dive depth of 100 fsw to find the residual nitrogen time of 7 minutes.

6. Add the 7 minutes of residual nitrogen time to the estimated bottom time of 15 minutes to obtain the single equivalent dive time of 22 minutes.

7. The diver will be decompressed on the 100/22 No-Decompression schedule.

Figure 9-9 depicts the dive profile for the first dive, Figure 9-10 shows the Repetitive Dive Worksheet, and Figure 9-11 shows the dive profile for the repetitive dive.

9-9.1.2 **RNT Exception Rule.** 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. If on a third or more dive and the RNT exception rule applies, add the equivalent single dive time of the previous dive to the repetitive dive. (All of

DIVING CHART - AIR (1126)

Date: 3 Feb 96			
NAME OF DIVER 1: ENC (MDV) Alogna	DIVING APPARATUS: MK-21	TYPE DRESS: Wet Suit	EGS (PSIG): 2750
NAME OF DIVER 2: CAPT McCord	DIVING APPARATUS: MK-21	TYPE DRESS: Wet Suit	EGS (PSIG): 2750
TENDERS (DIVER 1): BM1 Rotan AND QMC Troedel		TENDERS (DIVER 2): EN2 P. Johnson AND MM1 Peck	
LEFT SURFACE (LS): 1000	DEPTH (fsw): 100 + 1 = (101)	REACHED BOTTOM (RB): ~~1002~~	DESCENT TIME: :02
LEFT BOTTOM (LB): 1048	TOTAL BOTTOM TIME (TBT): :48	TABLE & SCHEDULE USED: 110/50 Std Air	TIME TO FIRST STOP: :02::40
REACHED SURFACE (RS): 1125::20	TOTAL DECOMPRESSION TIME (TDT): :37::20	TOTAL TIME OF DIVE (TTD): 01:25::20	REPETITIVE GROUP: M

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::20	10	:26		L 1125::00 R 1059::00	
	::20	20	:08		L 1058::40 R 1050::40	
	2::40	30			L R	
		40			L R	
		50			L R	
75	30	60			L R	
fpm	fpm	70			L R	
		80			L R	
		90			L R	
:02		100			L 1048 R 1002	
		110			L R	
		120			L R	
		130			L R	

PURPOSE OF DIVE: Training	REMARKS: OK to Repet
DIVER'S CONDITION: OK	DIVING SUPERVISOR: HTCM (MDV) Selby

Figure 9-9. Dive Profile.

REPETITIVE DIVE WORKSHEET

Date: 3 FEB 96

1st DIVE							
Max Depth	100 + 1 = 100						
Bottom Time	:48						
Table & Schedule	110/50 Std Air					**REPET Group**	M
Surface Interval	6:26					**New Group**	B
2nd DIVE							
Max Depth		**MD + ESDT = Table & Schedule**					
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
:15	+	:07	=	:22	=	100/22 No "D"	G
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	
3rd DIVE							
Max Depth		**MD + ESDT = Table & Schedule**					
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		=		=		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	
4th DIVE							
Max Depth		**MD + ESDT = Table & Schedule**					
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		=		=		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	

Figure 9-10. Repetitive Dive Worksheet.

DIVING CHART - AIR (1811)

DIVING CHART - AIR	1811		Date 3 Feb 96
NAME OF DIVER 1: ENC (MDV) Alogna	DIVING APPARATUS: MK-21	TYPE DRESS: Wet Suit	EGS (PSIG): 2500
NAME OF DIVER 2: CAPT McCord	DIVING APPARATUS: MK-21	TYPE DRESS: Wet Suit	EGS (PSIG): 2500
TENDERS (DIVER 1): HM2 Craig AND IC1 Akins		TENDERS (DIVER 2): CDR Barcus AND MMC Donato	
LEFT SURFACE (LS): 1752	DEPTH (fsw): 93 + 1 = 94	REACHED BOTTOM (RB): ~~1754~~	DESCENT TIME: :02
LEFT BOTTOM (LB): 1807	TOTAL BOTTOM TIME (TBT): :15 + RNT :07 = :22	TABLE & SCHEDULE USED: 100/22 No "D"	TIME TO FIRST STOP: :03::06
REACHED SURFACE (RS): 1810::06	TOTAL DECOMPRESSION TIME (TDT): :03::06	TOTAL TIME OF DIVE (TTD): :18::06	REPETITIVE GROUP: G

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	3::06	10			L	
					R	
		20			L	
					R	
		30			L	
					R	
		40			L	
					R	
		50			L	
					R	
75	30	60			L	
					R	
fpm	fpm	70			L	
					R	
		80			L	
					R	
		90			L	
					R	
:02		93 ~~100~~			L 1807	
					R ~~1754~~	
		110			L	
					R	
		120			L	
					R	
		130			L	
					R	

PURPOSE OF DIVE: Survey	REMARKS: OK to Repet
DIVER'S CONDITION: OK	DIVING SUPERVISOR: CUCM (MDV) Heirholzer

Figure 9-11. Dive Profile for Repetitive Dive.

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.)

9-10 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, significantly reducing the time that a diver must spend in the water. Also, breathing oxygen in the recompression chamber reduces the diver's total decompression time. Other variations will be handled in accordance with paragraph 9-6.2.

Surface decompression offers many advantages that enhance the divers' safety. Shorter exposure time in the water keeps divers from chilling to a dangerous level. Inside the recompression chamber, the divers can be maintained at a constant pressure, unaffected by surface conditions of the sea. Divers shall be observed constantly by either the inside tender or topside personnel, and monitored for decompression sickness and oxygen toxicity. Using an inside tender when two divers undergo surface decompression is at the discretion of the dive supervisor. If an inside tender is not used, both divers will carefully monitor each other in addition to being closely observed by topside personnel.

If oxygen is available in the recompression chamber, conduct surface decompression according to the Surface Decompression Table Using Oxygen (Table 9-10). If air is the only breathing medium available, use the Surface Decompression Table Using Air (Table 9-11).

Residual Nitrogen Timetables have not been developed for Surface Decompression Repetitive Dives. Repetitive surface decompression dives may be accomplished in accordance with paragraph 9-10.1.4.

9-10.1 Surface Decompression Table Using Oxygen. Using the Surface Decompression Table Using Oxygen (referred to as Sur D O_2) requires an approved double-lock recompression chamber with an oxygen breathing system as described in Chapter 21. With Sur D O_2, divers ascend at a constant rate of 30 fpm. 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 a half (:03:30) minutes to remove the breathing apparatus and diving dress and assist the divers into the recompression chamber.

Pressurizing 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 5 minutes**. During descent in the recompression chamber, if a diver cannot clear and the chamber is at a depth of at least 20 fsw, stop, then 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 prescribed surface interval is exceeded and the divers are asymptomatic, treat them as if they have Type I decompression sickness (Treatment Table 5, Chapter 20). If the divers are symptomatic, they are treated as if they have Type II decompression sickness (Chapter 20), even if they are only displaying Type I symptoms. Symptoms occurring during the chamber stops are treated as recurrences (Chapter 20).

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 mask should be strapped on both divers to ensure a good oxygen seal. The designated 40 foot stop time commences once the divers are breathing oxygen. The divers breathe oxygen throughout the 40 foot stop, interrupting 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, remove oxygen and commence traveling to the surface at 30 fpm. This procedure simplifies time keeping and should be used whenever using the Surface Decompression Table Using Oxygen. Remove the O_2 mask prior to leaving the 40 fsw stop for the surface.

9-10.1.1 **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 9-12 shows this dive profile.

In the event of oxygen system failure, it is important to be familiar with the appropriate air decompression schedules. If the oxygen system fails while the divers are in the water, the divers are shifted to the Standard Air Decompression Table (9-9) or the Surface Decompression Table Using Air (9-11). During the chamber phase, use the procedures listed below in the event of oxygen system failure or CNS oxygen toxicity.

9-10.1.2 **Loss of Oxygen Supply in the Chamber (40 fsw Chamber Stop).** If the oxygen supply in the chamber is lost at the 40 fsw chamber stop, have the diver breathe chamber air.

- **Temporary Loss**. Return the diver to oxygen breathing. Consider any time on air as dead time.

- **Permanent Loss**. Multiply the remaining oxygen time by three to obtain the equivalent chamber decompression time on air. If 50% helium 50% oxygen or 50% nitrogen 50% oxygen is available, multiply the remaining oxygen time by two to obtain the equivalent chamber decompression time on 50/50. Allocate 10% of the equivalent air or 50/50 time to the 40-fsw stop, 20% to the 30 fsw stop, and 70% to the 20 fsw stop. Round the stop times up to the next whole minute. Surface upon completion of the 20 fsw stop.

DIVING CHART - AIR

DIVING CHART - AIR	1044		Date: 11 Dec 96
NAME OF DIVER 1: BMCM (MDV) Augustine	DIVING APPARATUS: MK-21	TYPE DRESS: Wet Suit	EGS (PSIG): 2800
NAME OF DIVER 2: HMCS Thrift	DIVING APPARATUS: MK-21	TYPE DRESS: Wet Suit	EGS (PSIG): 2800
TENDERS (DIVER 1): EMC Favara AND GM2 Dumke		TENDERS (DIVER 2): HT1 Lutz AND HTC Tochterman	
LEFT SURFACE (LS): 0900	DEPTH (fsw): 152 + 2 = 154	REACHED BOTTOM (RB): ~~0903~~	DESCENT TIME: :03
LEFT BOTTOM (LB): 0940	TOTAL BOTTOM TIME (TBT): :40	TABLE & SCHEDULE USED: 160/40 Sur 'D' 02	TIME TO FIRST STOP: :03::24
REACHED SURFACE (RS): 1001::04/1043::24	TOTAL DECOMPRESSION TIME (TDT): 01:03::24	TOTAL TIME OF DIVE (TTD): 01:43::24	REPETITIVE GROUP: N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER		TIME WATER	TIME CHAMBER
	::01 / :01::20	10			L		
					R		
	:03::30 + ::30 = :04 / 80 fpm	20			L		
					R		
		30	:08		L	1000::04	
					R	0952::04	
	::20	40	:05	:30 02 :05 Air :02 02	L	0951::44	1042::04
					R	0946::44	1005::04
	::20	50	:03		L	0946::24	
					R	0943::24	
	3::24	60			L		
					R		
75	30	70			L		
					R		
fpm	fpm	80			L		
					R		
		90			L		
					R		
		100			L		
					R		
		110			L		
					R		
		120			L		
					R		
		152 ~~130~~			L	0940	
					R	~~0903~~	

PURPOSE OF DIVE: Training	REMARKS: OK to Repet
DIVER'S CONDITION: OK	DIVING SUPERVISOR: BMCS (MDV) Gaillard

Figure 9-12. Dive Profile.

Example. The oxygen supply to the chamber is lost at 10 minutes and 50/50 is not available. The original surface decompression using oxygen schedule called for a 20-min. oxygen stop.

Solution. The remaining oxygen time is 10 minutes (20-10). The equivalent chamber decompression time on air is 30 minutes (3 x 10). The 30 minutes of air stop time should be allocated as follows: Three minutes at 40 fsw (30 x 0.1), 6 minutes at 30 fsw (30 x 0.2), and 21 minutes at 20 fsw (30 x 0.7).

9-10.1.3 **CNS Oxygen Toxicity (40 fsw Chamber Stop).** At the first sign of CNS toxicity, the patient should be removed from oxygen and allowed to breathe chamber air. Fifteen minutes after all symptoms have completely subsided, resume oxygen breathing at the point of interruption. If symptoms of CNS oxygen toxicity develop again or if the first symptom is a convulsion, take the following action:

1. Remove the mask.

2. After all symptoms have completely subsided, decompress 10 feet at a rate of 1 fsw/min. For a convulsion, begin travel when the patient is fully relaxed and breathing normally.

3. Resume oxygen breathing at the shallower depth at the point of interruption.

4. If another oxygen symptom occurs, complete decompression time on air. Multiply the remaining oxygen time by three to obtain the equivalent chamber decompression time on air. Allocate 30% of the equivalent air to the 30 fsw stop and 70% to the 20 fsw stop. Surface upon completion of the 20 fsw stop.

9-10.1.3.1 ***Example.*** The diver has a third oxygen symptom after completing 28 minutes of the required decompression. The diver is at 30 fsw based on the second oxygen symptom protocol. The original surface decompression using oxygen schedule called for a 38 min. oxygen stop.

9-10.1.3.2 ***Solution.*** The remaining oxygen time is 10 minutes (38-28). The equivalent chamber decompression time on air is 30 minutes (3 x 10). The 30 minutes of air stop time should be allocated as follows: Nine minutes at 30 fsw (30 x 0.3) and 21 minutes at 20 fsw (30 x 0.7).

9-10.1.4 **Repetitive Dives.** 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, select the appropriate decompression schedule by:

1. Adding the bottom times of all dives made in the previous 12 hours to get an adjusted bottom time, and

2. Using the maximum depth obtained in the previous 12 hours.

DIVING CHART - AIR

1059 (circled)

Date: 16 Aug 96

NAME OF DIVER 1 CUCM (MDV) Knopick	DIVING APPARATUS MK-21	TYPE DRESS Swim	EGS (PSIG) 2750
NAME OF DIVER 2 Dr. Flynn	DIVING APPARATUS MK-21	TYPE DRESS Swim	EGS (PSIG) 2750
TENDERS (DIVER 1) LCDR Randall AND CM1 Loeffler		TENDERS (DIVER 2) SW1 Koeble AND BMC Brown	
LEFT SURFACE (LS) 0900	DEPTH (fsw) 152 + 2 = 154 (circled)	REACHED BOTTOM (RB) ~~0903~~	DESCENT TIME :03
LEFT BOTTOM (LB) 0940	TOTAL BOTTOM TIME (TBT) :40	TABLE & SCHEDULE USED 160/40 Sur 'D' 02	TIME TO FIRST STOP 0:03::24
REACHED SURFACE (RS) 1001::04/1058::24	TOTAL DECOMPRESSION TIME (TDT) 01:18::24	TOTAL TIME OF DIVE (TTD) 01:58::24	REPETITIVE GROUP N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME: WATER	DECOMPRESSION TIME: CHAMBER	TIME: WATER	TIME: CHAMBER
	:01 / :01::20	10			L R	
	:03::30	20			L R	
	80 fpm + ::30 = :04	30	:08		L 1000::04 R 0952::04	
	:20	40	:05	:12 02 :05 Air :15 Air :20 02	L 0951::44 R 0946::44	1057::04 1005::04
	:20	50	:03		L 0946::24 R 0943::24	
	3::24	60			L R	
		70			L R	
75	30	80			L R	
fpm	fpm	90			L R	
		100			L R	
		110			L R	
		120			L R	
:03		152 ~~130~~			L 0940 R ~~0903~~	

PURPOSE OF DIVE Requal	REMARKS 02 Symptom :12 into 40 FSW chamber stop off 02 subsided in :05 waited :15. Resumed 02 at point of interruption
DIVER'S CONDITION OK	DIVING SUPERVISOR HTCM (MDV) Young

Figure 9-13. Dive Profile.

3. The equivalent single dive shall not exceed 170/40 for Sur D O_2 or 190/60 for Sur D Air.

9-10.1.4.1 ***Example.*** A dive is conducted to 165 fsw for 25 minutes, followed by a surface interval of 3 hours 42 minutes, and a repetitive dive to 133 fsw for 15 minutes. The Surface Decompression Table Using Oxygen is used for both dives. Determine the correct decompression schedules.

9-10.1.4.2 ***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 40 minutes. Figure 9-14, Figure 9-15, and Figure 9-16 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.

9-10.2 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 surface decompression using air are getting the divers out of the water sooner 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 3½ 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 5 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 or Air Treatment Table 1A, Chapter 20). If the divers are symptomatic, they are treated as if they had Type II Decompression Sickness (Treatment Table 6 or Air Treatment Table 2A, Chapter 20), even if they are only displaying Type I symptoms. Symptoms occurring during the chamber stops are treated as recurrences (Chapter 20).

9-10.2.1 **Example.** A dive is conducted to 123 fsw for 48 minutes using the Surface Decompression Table Using Air. Determine the correct decompression schedule.

9-10.2.2 **Solution.** The correct decompression schedule for a dive conducted to 123 fsw for 48 minutes is the 130/50 schedule. The decompression chart is shown in Figure 9-17.

DIVING CHART - AIR

0855

			Date 1 Aug 96
NAME OF DIVER 1 BMCS (MDV) Smith	DIVING APPARATUS MK-21	TYPE DRESS Swim	EGS (PSIG) 2900
NAME OF DIVER 2 EN1 McCullough	DIVING APPARATUS MK-21	TYPE DRESS Swim	EGS (PSIG) 2900

TENDERS (DIVER 1) CWO Harris AND CDR Christensen	TENDERS (DIVER 2) CWO Spisak AND LCDR O'Rourke

LEFT SURFACE (LS) 0800	DEPTH (fsw) 165 + 2 = 167	REACHED BOTTOM (RB) ~~0803~~	DESCENT TIME :03
LEFT BOTTOM (LB) 0825	TOTAL BOTTOM TIME (TBT) :25	TABLE & SCHEDULE USED 170/25 Sur 'D' 02	TIME TO FIRST STOP 5::30
REACHED SURFACE (RS) 0830::30/0854::50	TOTAL DECOMPRESSION TIME (TDT) :29::50	TOTAL TIME OF DIVE (TTD) :54::50	REPETITIVE GROUP N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	5::30; :01::20	10			L R	
	3::30 + ::30 = :04; 80 fpm	20			L R	
		30			L R	
		40		:19 O2	L R	0853::30 0834::30
		50			L R	
75	30	60			L R	
fpm	fpm	70			L R	
		80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
:03		165 ~~130~~			L 0825 R ~~0803~~	

PURPOSE OF DIVE Requal	REMARKS OK to Repet
DIVER'S CONDITION OK	DIVING SUPERVISOR HTCM (MDV) Furr

Figure 9-14.

REPETITIVE DIVE WORKSHEET							Date: 1 Aug 96
1st DIVE							
Max Depth	165 + 2 = 167						
Bottom Time	:25						
Table & Schedule	170/25 Sur "D" 02					**REPET Group**	N/A
Surface Interval	4:27					**New Group**	N/A
2nd DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
:15	+	:25	=	:40	=	170/40 Sur "D" 02	N/A
Ensure the RNT Exception Rule does not apply (diver "maxed out" on Sur "D" 02)							
Surface Interval						**New Group**	
3rd DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		=		=		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	
4th DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		=		=		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	

Figure 9-15. Repetitive Dive Worksheet.

9-10.2.3 **Repetitive Dives.** If a second surface decompression air dive is planned within a 12-hour period, the same rule applies as for making a second Sur D O_2 dive (paragraph 9-10.1.4).

9-10.2.3.1 ***Example.*** A repetitive Sur D Air dive is planned for 138 fsw for 20 minutes. The previous dive was to 167 fsw for 30 minutes. The surface interval was 4 hours 27 minutes. Determine the correct decompression schedules.

9-10.2.3.2 ***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. Figure 9-18 illustrates the first dive, the repetitive dive worksheet is shown in Figure 9-19 and the repetitive dive for the example above is shown in Figure 9-20.

DIVING CHART - AIR

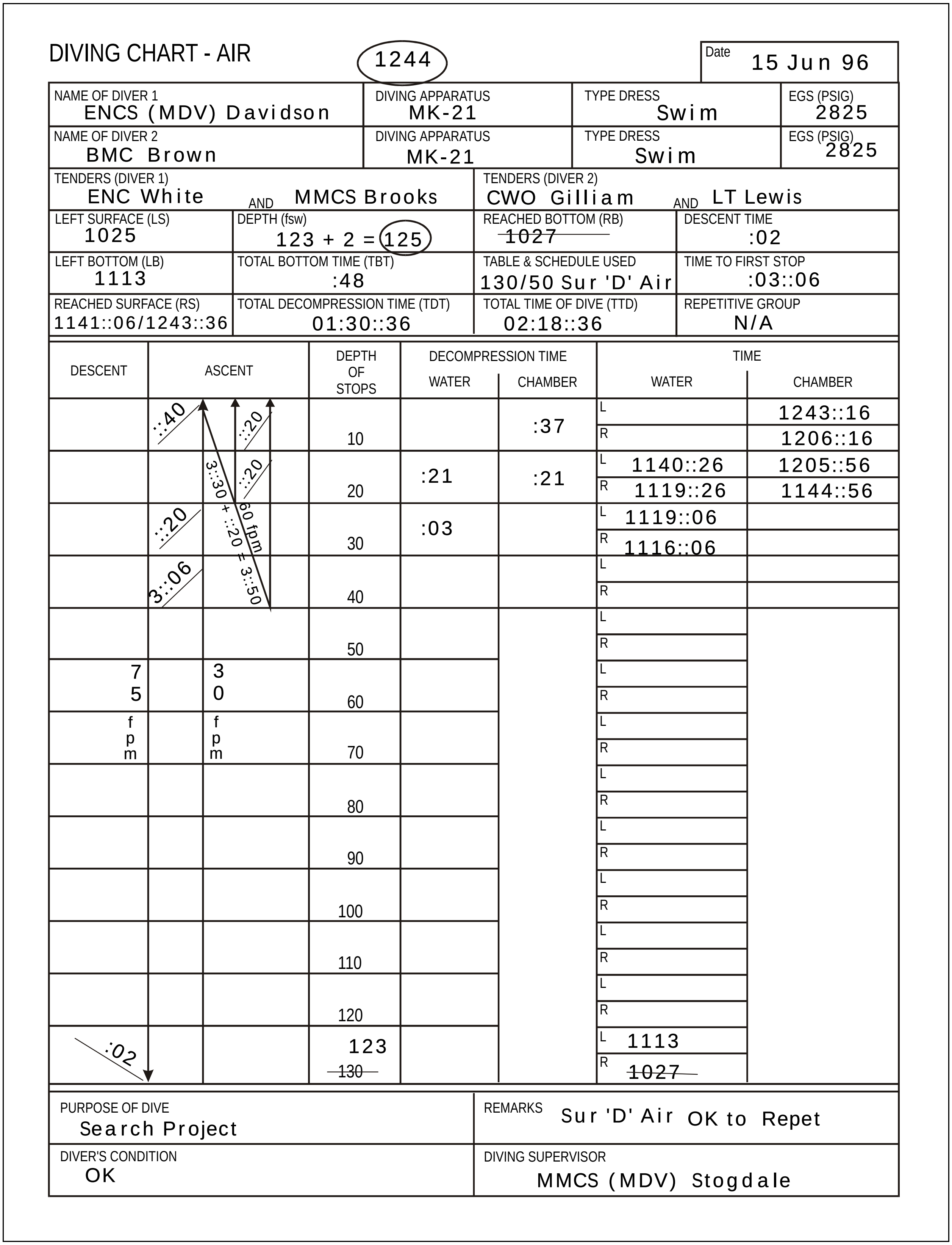
(1405)

			Date: 1 Aug 96
NAME OF DIVER 1: BMCS (MDV) Smith	DIVING APPARATUS: MK-21	TYPE DRESS: Swim	EGS (PSIG): 2900
NAME OF DIVER 2: BM1 Starring	DIVING APPARATUS: MK-21	TYPE DRESS: Swim	EGS (PSIG): 2900
TENDERS (DIVER 1): CAPT. Rewick AND *LCDR Veazie*		TENDERS (DIVER 2): CWO Schnieder AND CDR. Coster	
LEFT SURFACE (LS): 1237	DEPTH (fsw): 133 + 2 = (135)	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' 02	TIME TO FIRST STOP: :02::26
REACHED SURFACE (RS): 1318::26/1404::46	TOTAL DECOMPRESSION TIME (TDT): 01:12::46	TOTAL TIME OF DIVE (TTD): 01:27::46	REPETITIVE GROUP: N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::01; .01::20	10			L	
					R	
	3::30 + ::30 = :04; 80 fpm	20			L	
					R	
		30	:06		L 1317::26	
					R 1311::26	
	::20	40	:08	:30 02 :05 Air :06 02	L 1311::06	1403::26
					R 1303::06	1322::26
	::20	50	:04		L 1302::46	
					R 1258::46	
	::20	60	:04		L 1258::26	
					R 1254::26	
	2::26	70			L	
					R	
75	30	80			L	
					R	
fpm	fpm	90			L	
					R	
		100			L	
					R	
		110			L	
					R	
		120			L	
					R	
:02		133			L 1252	
		~~130~~			R ~~1239~~	

PURPOSE OF DIVE: Training	REMARKS: Do Not Repet Maxed Out Sur 'D' 02
DIVER'S CONDITION: OK	DIVING SUPERVISOR: SWCS (MDV) Isui

Figure 9-16. Dive Profile.



DIVING CHART - AIR (1244)

Date: 15 Jun 96

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
ENCS (MDV) Davidson	MK-21	Swim	2825
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)
BMC Brown	MK-21	Swim	2825

TENDERS (DIVER 1)	TENDERS (DIVER 2)
ENC White AND MMCS Brooks	CWO Gilliam AND LT Lewis

LEFT SURFACE (LS)	DEPTH (fsw)	REACHED BOTTOM (RB)	DESCENT TIME
1025	123 + 2 = (125)	~~1027~~	:02
LEFT BOTTOM (LB)	TOTAL BOTTOM TIME (TBT)	TABLE & SCHEDULE USED	TIME TO FIRST STOP
1113	:48	130/50 Sur 'D' Air	:03::06
REACHED SURFACE (RS)	TOTAL DECOMPRESSION TIME (TDT)	TOTAL TIME OF DIVE (TTD)	REPETITIVE GROUP
1141::06/1243::36	01:30::36	02:18::36	N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER		TIME WATER	TIME CHAMBER
	::40, ::20	10		:37	L		1243::16
					R		1206::16
	::20	20	:21	:21	L	1140::26	1205::56
					R	1119::26	1144::56
	::20, 60 fpm	30	:03		L	1119::06	
					R	1116::06	
	3::06, 3::30 + ::20 = 3::50	40			L		
					R		
		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		123 ~~130~~			L	1113	
					R	~~1027~~	

PURPOSE OF DIVE	REMARKS
Search Project	Sur 'D' Air OK to Repet
DIVER'S CONDITION	DIVING SUPERVISOR
OK	MMCS (MDV) Stogdale

Figure 9-17. Dive Profile.

DIVING CHART - AIR

1548 (circled)

Date 20 Nov 96			
NAME OF DIVER 1 BMCM (MDV) Cambell	DIVING APPARATUS MK-21	TYPE DRESS Wetsuit	EGS (PSIG) 2850
NAME OF DIVER 2 HMC Juarez	DIVING APPARATUS MK-21	TYPE DRESS Wetsuit	EGS (PSIG) 2850
TENDERS (DIVER 1) CWO Armstrong AND CWO Miller		TENDERS (DIVER 2) CWO Nelson AND MMC Jalbert	
LEFT SURFACE (LS) 1400	DEPTH (fsw) 169 + 2 = 171 (circled)	REACHED BOTTOM (RB) ~~1403~~	DESCENT TIME :03
LEFT BOTTOM (LB) 1430	TOTAL BOTTOM TIME (TBT) :30	TABLE & SCHEDULE USED 180/30 Sur 'D' Air	TIME TO FIRST STOP :04::34
REACHED SURFACE (RS) 1458::38/1547::08	TOTAL DECOMPRESSION TIME (TDT) 01:17::08	TOTAL TIME OF DIVE (TTD) 01:47::08	REPETITIVE GROUP N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::40 ::20	10		:27	L R	1546::48 1519::48
	::20 3::30 + ::20 = 3::50 60 fpm	20	:17	:17	L 1457::58 R 1440::58	1519::28 1502::28
	::20	30	:06		L 1440::38 R 1434::38	
	4::34	40			L R	
		50			L R	
75	30	60			L R	
fpm	fpm	70			L R	
		80			L R	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
:03		169 ~~130~~			L 1430 R ~~1403~~	

PURPOSE OF DIVE Survey Crash Debris	REMARKS Sur 'D' Air OK to Repet
DIVER'S CONDITION OK	DIVING SUPERVISOR HTCS (MDV) Heineman

Figure 9-18. Dive Profile.

9-11 EXCEPTIONAL EXPOSURE DIVES

Exceptional exposure dives are those dives in which the risk of decompression sickness, oxygen toxicity, and/or exposure to the elements is substantially greater than on normal working dives. Decompression schedules for exceptional exposure dives are contained in the Standard Air Decompression Table. These exceptional exposure schedules are intended to be used only in emergencies, such as diver entrapment. Exceptional exposure dives should not be planned in advance except under the most unusual operational circumstances. The Commanding Officer must carefully assess the need for planned exceptional exposure diving and prior CNO approval for such diving is required. 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.

9-11.1 Surface Decompression Procedures for Exceptional Exposure Dives. The long decompressions times associated with exceptional exposure dives impose unusual demands on a diver's endurance. There is also limited assurance that the dive will be completed without decompression sickness. These two risks can be reduced by using surface decompression techniques rather than completing decompression entirely in the water.

9-11.1.1 **If oxygen is available at the 30 fsw stop in the water:**

1. Complete the entire 30 fsw in water stop on oxygen, interrupting oxygen breathing after each 30 minutes with a 5 minute air break. The air breaks count as part of the stop time.

2. Ascend to the surface at 30 fpm. Minor variations in the rate of travel between 20 and 40 fpm are acceptable.

3. Once on the surface, the tenders have three and a half (:03:30) minutes to remove the breathing apparatus and diving dress and assist the divers into the recompression chamber.

4. Pressurize the recompression chamber with air to 30 fsw at a travel rate of 60 fpm.

5. Upon arrival at 30 fsw in the recompression chamber, the divers are placed on the Built-in Breathing System (BIBS) mask breathing 100% oxygen.

6. The 30 foot stop time commences once the divers are breathing oxygen. Repeat the 30 fsw in-water stop time.

7. The divers breathe oxygen throughout the 30-foot stop, interrupting oxygen breathing after each 30 minutes with a 5 minute air break. The air breaks count as part of the stop time.

8. Ascend to 20 fsw at 30 fpm. Complete the 20 fsw in-water stop time. The divers breathe oxygen throughout the 20-foot stop, interrupting oxygen breath-

REPETITIVE DIVE WORKSHEET

Date: 20 Nov 96

1st DIVE			
Max Depth	169 + 2 = 171		
Bottom Time	:30		
Table & Schedule	180/30 Sur "D" Air	**REPET Group**	N/A
Surface Interval	4:27	**New Group**	N/A

2nd DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
:20	+	:30	=	:50	=	180/50 Sur "D" Air	N/A
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	

3rd DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		=		=		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	

4th DIVE							
Max Depth			**MD + ESDT = Table & Schedule**				
Bottom Time	**+**	**RNT**	**=**	**ESDT**	**=**	**Table & Schedule**	**REPET Group**
	+		=		=		
Ensure the RNT Exception Rule does not apply							
Surface Interval						**New Group**	

Figure 9-19. Repetitive Dive Worksheet.

ing after each 30 minutes with a 5 minute air break. The air breaks count as part of the stop time.

9. Ascend to 10 fsw at 30 fpm. Complete the 10 fsw in-water stop time. The divers breathe oxygen throughout the 10-foot stop, interrupting oxygen breathing after each 30 minutes with a 5 minute air break. The air breaks count as part of the stop time.

10. Ascent to the surface at 30 fpm.

9-11.1.2 **If no oxygen is available at the 30 fsw stop in the water:**

1. Complete the entire 20 fsw in the water.

2. Ascend to the surface at 30 fpm. Minor variations in the rate of travel between 20 and 40 fpm are acceptable.

3. Once on the surface, the tenders have three and a half (:03:30) minutes to remove the breathing apparatus and diving dress and assist the divers into the recompression chamber.

4. Pressurize the recompression chamber with air to 20 fsw at a travel rate of 60 fpm.

5. Upon arrival at 20 fsw in the recompression chamber, the divers are placed on the Built-in Breathing System (BIBS) mask breathing 100% oxygen.

6. The 20 foot stop time commences once the divers are breathing oxygen. Repeat the 20 fsw in-water stop time.

7. The divers breathe oxygen throughout the 20-foot stop, interrupting oxygen breathing after each 30 minutes with a 5 minute air break. The air breaks count as part of the stop time.

8. Ascend to 10 fsw at 30 fpm. Complete the 10 fsw in-water stop time. The divers breathe oxygen throughout the 10-foot stop, interrupting oxygen breathing after each 30 minutes with a 5 minute air break. The air breaks count as part of the stop time.

9. Ascent to the surface at 30 fpm.

9-11.2 **Oxygen System Failure (Chamber Stop).** If the oxygen systems fails during a chamber stop, complete the remaining decompression time on air.

DIVING CHART - AIR

2320

NAME OF DIVER 1 BMCM (MDV) Cambell	DIVING APPARATUS MK-21	TYPE DRESS Wetsuit	EGS (PSIG) 2850
NAME OF DIVER 2 HMC Juarez	DIVING APPARATUS MK-21	TYPE DRESS Wetsuit	EGS (PSIG) 2850
TENDERS (DIVER 1) BM1 Dobbs AND HTCS Patterson		TENDERS (DIVER 2) BMC Sackman AND HMC Polli	
LEFT SURFACE (LS) 2015	DEPTH (fsw) 139 + 2 = 141	REACHED BOTTOM (RB) ~~2017~~	DESCENT TIME :02
LEFT BOTTOM (LB) 2035	TOTAL BOTTOM TIME (TBT) :20 + :30 = :50	TABLE & SCHEDULE USED 180/50 Sur 'D' Air	TIME TO FIRST STOP :02::58
REACHED SURFACE (RS) 2139::18/2318::58	TOTAL DECOMPRESSION TIME (TDT) 02:43::58	TOTAL TIME OF DIVE (TTD) 03:03::58	REPETITIVE GROUP N/A

Date: 20 Nov 96

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER		TIME WATER	TIME CHAMBER
	::40 ::20	10		:65	L		2318::38
					R		2213::38
	::20 3::30	20	:30	:30	L	2138::58	2213::08
					R	2108::58	2143::08
	::20 + ::20 60 fpm	30	:19		L	2108::38	
					R	2049::38	
	::20 = 3::50	40	:09		L	2049::18	
					R	2040::18	
	::20	50	:02		L	2039::58	
					R	2037::58	
	:02::56	60			L		
					R		
75	30	70			L		
					R		
fpm	fpm	80			L		
					R		
		90			L		
					R		
		100			L		
					R		
		110			L		
					R		
		120			L		
					R		
:02		139 ~~130~~			L	2035	
					R	~~2017~~	

PURPOSE OF DIVE Recover Debris	REMARKS Sur 'D' Air OK to Repet
DIVER'S CONDITION OK	DIVING SUPERVISOR EMCM (MDV) Propster

Figure 9-20. Dive Profile.

9-12 DIVING AT HIGH ALTITUDES

Because of the reduced atmospheric pressure, dives conducted at altitude require more decompression than identical dives conducted at sea level. Standard air decompression tables, therefore, cannot be used as written. Some organizations calculate specific decompression tables for use at each altitude. An alternative approach is to correct the altitude dive to obtain an equivalent sea level dive, then determine the decompression requirement using standard tables. This procedure is commonly known as the “Cross Correction” technique and always yields a sea level dive that is deeper than the actual dive at altitude. A deeper sea level equivalent dive provides the extra decompression needed to offset effects of diving at altitude.

9-12.1 Altitude Correction Procedure. To apply the “Cross Correction” technique, two corrections must be made for altitude diving. First, the actual dive depth must be corrected to determine the sea level equivalent depth. Second, the decompression stops in the sea level equivalent depth table must be corrected for use at altitude. Strictly speaking, ascent rate should also be corrected, but this third correction can safely be ignored.

9-12.1.1 **Correction of Depth of Dive.** Depth of a sea level equivalent dive is determined by multiplying the depth of the dive at altitude by a ratio of atmospheric pressure at sea level to atmospheric pressure at altitude. Using millibars (mb) as a unit for expressing atmospheric pressure at altitude equivalent depth is then:

$$\text{Equivalent Depth (fsw)} = \text{Altitude Depth (fsw)} \times \frac{\text{Pressure at Sea Level (mb)}}{\text{Pressure at Altitude (mb)}}$$

Example: A diver makes a dive to 60 fsw at an altitude of 5000 ft. The atmospheric pressure measured at 5000 ft is 843 millibars (0.832 ATA). Atmospheric pressure at sea level is assumed to be 1013 millibars (1.000 ATA). Sea level equivalent depth is then:

$$\text{Equivalent Depth (fsw)} = 60\ \text{fsw} \times \frac{1013\ \text{mb}}{843\ \text{mb}} = 72.1\ \text{fsw}$$

9-12.1.2 **Correction for Decompression Stop Depths.** Depth of the corrected stop at altitude is calculated by multiplying depth of a sea level equivalent stop by a ratio of atmospheric pressure at altitude to atmospheric pressure at sea level. [Note: this ratio is inverse to the ratio in the formula above.

$$\text{Altitude Stop Depth (fsw)} = \text{Sea Level Stop Depth (fsw)} \times \frac{\text{Pressure at Altitude (mb)}}{\text{Pressure at Sea Level (mb)}}$$

Example: A diver makes a dive at an altitude of 5000 ft. An equivalent sea level dive requires a decompression stop at 20 fsw. Stop depth used at altitude is then:

$$\text{Altitude Stop Depth (fsw)} = 20 \text{ fsw} \times \frac{843 \text{ mb}}{1013 \text{ mb}} = 16.6 \text{ fsw}$$

To simplify calculations, Table 9-4 gives corrected sea level equivalent depths and equivalent stops depths for dives from 10-190 ft and for altitudes from 1,000 to 10,000 ft in 1000 ft increments.

WARNING **Table 9-4 cannot be used with constant ppO_2 diving equipment, such as the MK 16.**

9-12.2 **Need for Correction.** No correction is required for dives conducted at altitudes between sea level and 300 ft. The additional risk associated with these dives is minimal. At altitudes between 300 and 1000 feet, correction is required for dives deeper than 145 fsw (actual depth). At altitudes above 1000 ft., correction is required for all dives.

9-12.3 **Depth Measurement at Altitude.** The preferred method for measuring depth at altitude is a mechanical or electronic gauge that can be re-zeroed at the dive site. Once re-zeroed, no further correction of the reading is required.

When using a recompression chamber for decompression, zero the chamber depth gauges before conducting surface decompression.

Most mechanical depth gauges carried by divers have a sealed one atmosphere reference and cannot be adjusted for altitude, thus they will read low throughout a dive at altitude. A correction factor of 1 fsw for every 1000 ft of altitude should be added to the reading of a sealed reference gauge before entering Table 9-4.

Pneumofathometers can be used at altitude. Add the pneumofathometer correction factor (Table 9-1) to the depth reading before entering Table 9-4. The pneumofathometer correction factors are unchanged at altitude.

A sounding line or fathometer may be used to measure the depth if a suitable depth gauge is not available. These devices measure the linear distance below the surface of the water, not the water pressure. Though fresh water is less dense than sea water, all dives will be assumed to be conducted in sea water, thus no corrections will be made based on water salinity. Enter Table 9-4 directly with the depth indicated on the line or fathometer.

Table 9-4. *Sea Level Equivalent Depth (fsw).*

Actual Depth (fsw)	Altitude (feet) 1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
10	10	15	15	15	15	15	15	15	15	15
15	15	20	20	20	20	20	20	25	25	25
20	20	25	25	25	25	25	30	30	30	30
25	25	30	30	30	35	35	35	35	35	40
30	30	35	35	35	40	40	40	50	50	50
35	35	40	40	50	50	50	50	50	50	60
40	40	50	50	50	50	50	60	60	60	60
45	45	50	60	60	60	60	60	70	70	70
50	50	60	60	60	70	70	70	70	70	80
55	55	60	70	70	70	70	80	80	80	80
60	60	70	70	70	80	80	80	90	90	90
65	65	70	80	80	80	90	90	90	100	100
70	70	80	80	90	90	90	100	100	100	110
75	75	90	90	90	100	100	100	110	110	110
80	80	90	90	100	100	100	110	110	120	120
85	85	100	100	100	110	110	120	120	120	130
90	90	100	110	110	110	120	120	130	130	140
95	95	110	110	110	120	120	130	130	140	140
100	100	110	120	120	130	130	130	140	140	150
105	105	120	120	130	130	140	140	150	150	160
110	110	120	130	130	140	140	150	150	160	160
115	115	130	130	140	140	150	150	160	170	170
120	120	130	140	140	150	150	160	170	170	180
125	125	140	140	150	160	160	170	170	180	190
130	130	140	150	160	160	170	170	180	190	190
135	135	150	160	160	170	170	180	190	190	200
140	140	160	160	170	170	180	190	190	200	210
145	145	160	170	170	180	190	190	200	210	
150	160	170	170	180	190	190	200	210		
155	170	170	180	180	190	200	210			
160	170	180	180	190	200	200				
165	180	180	190	200	200					
170	180	190	190	200						
175	190	190	200							
180	190	200	210							
185	200	200								
190	200									
Table Water Stops	**Equivalent Stop Depths (fsw)**									
10	10	9	9	9	8	8	8	7	7	7
20	19	19	18	17	17	16	15	15	14	14
30	29	28	27	26	25	24	23	22	21	21
40	39	37	36	35	33	32	31	30	29	28
50	48	47	45	43	42	40	39	37	36	34
60	58	56	54	52	50	48	46	45	43	41

Note: ▬▬▬ = Exceptional Exposure Limit

9-12.4 **Equilibration at Altitude.** Upon ascent to altitude, two things happen. The body off-gases excess nitrogen to come into equilibrium with the lower partial pressure of nitrogen in the atmosphere. It also begins a series of complicated adjustments to the lower partial pressure of oxygen. The first process is called equilibration; the second is called acclimatization. Twelve hours at altitude is required for equilibration. A longer period is required for full acclimatization.

If a diver begins a dive at altitude within 12 hours of arrival, the residual nitrogen left over from sea level must be taken into account. In effect, the initial dive at altitude can be considered a repetitive dive, with the first dive being the ascent from sea level to altitude. Table 9-5 gives the repetitive group associated with an initial ascent to altitude. Using this group and the time at altitude before diving, enter the Residual Nitrogen Timetable for Repetitive Air Dives (Table 9-8) to determine a new repetitive group designator associated with that period of equilibration. Determine sea level equivalent depth for your planned dive using Table 9-4. From your new repetitive group and sea level equivalent depth, determine the residual nitrogen time associated with the dive. Add this time to the actual bottom time of the dive.

Example: A diver ascends rapidly to 6000 feet in a helicopter and begins a dive to 100 fsw 90 minutes later. How much residual nitrogen time should be added to the dive?

From Table 9-5, repetitive group upon arrival at 6000 feet is Group E. During 90 minutes at altitude, the diver will desaturate to Group D. From Table 9-4, sea level equivalent depth for a 100 fsw dive is 130 fsw. From Table 9-8, residual nitrogen time for a 130 fsw dive in Group D is 11 minutes. The diver should add 11 minutes to bottom time.

Table 9-5 can also be used when a diver who is fully equilibrated at one altitude ascends to and dives at a higher altitude. Enter Table 9-5 with the difference between the two altitudes to determine an initial repetitive group.

Example: Divers equilibrated at a base camp altitude of 6000 feet, fly by helicopter to the dive site at 10,000 feet. The difference between the altitudes is 4000 feet. From Table 9-5, the initial repetitive group to be used at 10,000 feet is Group C.

WARNING **Altitudes above 10,000 feet can impose serious stress on the body resulting in significant medical problems while the acclimatization process takes place. Ascents to these altitudes must be slow to allow acclimatization to occur and prophylactic drugs may be required. These exposures should always be planned in consultation with a Diving Medical Officer. Commands conducting diving operations above 10,000 feet may obtain the appropriate decompression procedures from NAVSEA 00C.**

Table 9-5. *Repetitive Groups Associated with Initial Ascent to Altitude.*

Altitude (feet)	Repetitive Group
1000	A
2000	B
3000	B
4000	C
5000	D
6000	E
7000	E
8000	F
9000	G
10000	H

9-12.5 **Diving At Altitude Worksheet.** Figure 9-21 is a worksheet for altitude diving. To determine Sea Level Equivalent Depth (SLED) and corrected decompression stops for an altitude dive, follow these steps:

9-12.5.1 **Corrections for Depth of Dive at Altitude and In-Water Stops.**

Line 1. Determine dive site altitude by referring to a map. From Table 9-4, enter the altitude in feet that is equal to, or next greater than the altitude at the dive site.

Line 2. Enter the actual depth of the dive in feet of seawater.

NOTE **Refer to paragraph 9-12.3 to correct divers' depth gauge readings to actual depths at altitude.**

Line 3. Read Table 9-4 vertically down the Actual Depth column. Select a depth that is equal to or next greater than the actual depth. Reading horizontally, select the Sea Level Equivalent Depth corresponding to an altitude equal or next greater than that of your dive site.

9-12.5.2 **Corrections for Equilibration.**

Line 4. Enter the Repetitive Group upon arrival at altitude from Table 9-5 for the altitude listed on Line 1.

Line 5. Record time in hours and minutes spent equilibrating at altitude prior to the dive. If time at altitude is greater than 12 hours, proceed to step 7 and enter zero.

Line 6. Using Table 9-8, determine the Repetitive Group at the end of the pre-dive equilibration interval.

DIVING AT ALTITUDE WORKSHEET

DATE

Actual Dive Site Altitude ______ feet

1. Altitude from Table 9-3. ______ feet
2. Actual Depth of Dive (corrected per section 9-12.3) ______ fsw
3. Sea Level Equivalent Depth from Table 9-3 ______ SLED
4. Repetitive Group from Table 9-4 ______
5. Time at Altitude ______ hrs ______ min
6. New Repetitive Group Designation from Table 9-7 ______
7. Residual Nitrogen Time ______ min
8. Planned Bottom Time + ______ min
9. Equivalent Single Dive Time = ______ min
10. Decompression Table
    - ☐ Standard Air Table
    - ☐ Unlimited/No-Decompression Table
    - ☐ Surface Table Using Oxygen
    - ☐ Surface Table Using Air
11. Table/Schedule ______ / ______
12. Decompression Schedule

Sea Level Stop Depth	Altitude Stop Depth	Stop Time (Water/Chamber)
10 fsw	______ fsw	___ / ___ min
20 fsw	______ fsw	___ / ___ min
30 fsw	______ fsw	___ / ___ min
40 fsw	______ fsw	___ / ___ min*
50 fsw	______ fsw	______ min
60 fsw	______ fsw	______ min

13. Repetitive Group Letter Designation ______

*Chamber stop on SUR D O_2 will be at 40 fsw.

Figure 9-21. Worksheet for Diving at Altitude.

Line 7. Using Table 9-8, determine the Residual Nitrogen Time for the new repetitive group designation from line 6 and the Sea Level Equivalent Depth from line 3.

Line 8. Enter the planned bottom time.

Line 9. Add the bottom time and the residual nitrogen time to obtain the equivalent Single Dive Time.

Line 10. Select the Decompression Table to be used.

Line 11. Enter the Schedule from the Decompression Table using the Sea Level Equivalent Depth from line 3 and equivalent Single Dive Time from line 9.

Line 12. Using the lower section of Table 9-4, read down the Table Water Stops column on the left to the decompression stop(s) given in the Sea Level Equivalent Depth Table/Schedule. Read horizontally to the altitude column. Record the corresponding altitude stop depths on the worksheet.

NOTE **For surface decompression dives on oxygen, the chamber stops are not adjusted for altitude. Enter the same depths as at sea level. Keeping chamber stop depths the same as sea level provides an extra decompression benefit for the diver on oxygen. For surface decompression on air, stops must be adjusted. (See the example below and Figure 9-22.)**

Line 13. Record the Repetitive Group Designator at the end of the dive.

NOTE **Follow all decompression table procedures for ascent and descent**

Example: Five hours after arriving at an altitude of 7750 feet, divers make a 60 minute air dive to a gauge depth of 75 fsw. Depth is measured with a pneumofathometer having a non-adjustable gauge with a fixed reference pressure of one atmosphere. The Surface Decompression Table Using Oxygen will be used for decompression. What is the proper decompression schedule?

The altitude is first rounded up to 8000 feet. A depth correction of +8 fsw must be added to the maximum depth recorded on the fixed reference gauge. A pneumofathometer correction factor of + 1 fsw must also be added. The divers' actual depth is 84 fsw. Table 9-4 is entered at an actual depth of 85 fsw. The Sea Level Equivalent Depth for 8000 feet of altitude is 120 fsw. The repetitive group upon arrival at altitude is Group F. This decays to Group B during the five hours at altitude pre-dive. The residual nitrogen time for Group B at 120 fsw is 6 minutes. The Equivalent Single Dive Time therefore is 66 minutes. The appropriate decompression schedule from the Surface Decompression Table Using Oxygen is 120 fsw for 70 minutes. By the schedule, a 4-minute stop at 30 fsw in the water and a 39-minute stop at 40 fsw in the chamber are required. The water stop is taken at a depth of 22 fsw. The chamber stop is taken at a depth of 40 fsw.

Figure 9-22 shows the filled-out Diving at Altitude Worksheet for this dive. Figure 9-23 shows the filled-out Diving Chart.

9-12.6 Repetitive Dives. Repetitive dives may be conducted at altitude. The procedure is identical to that a sea level, with the exception that the sea level equivalent dive depth is always used to replace the actual dive depth. Figure 9-24 is a Repetitive Dive at Altitude Worksheet.

Example: Fourteen hours after ascending to an altitude of 7750 feet, divers make a 82 fsw 60 minute MK 21 dive using the Standard Air Table. Depth is measured with a pneumofathometer having a depth gauge adjustable for altitude. After two hours and 10 minutes on the surface, they make a second dive to 79 fsw for 30 minutes and decompress on the Surface Decompression Table Using Oxygen. What is the proper decompression schedule for the second dive?

The altitude is first rounded up to 8000 feet. For the first dive, a depth correction of +1 fsw must be added to the 82 fsw pneumofathometer reading. The divers actual depth on the first dive is 83 fsw. Table 9-4 is entered at an actual depth of 85 fsw. The Sea Level Equivalent Depth for the first dive is 120 fsw. The repetitive group designation upon completion of the 60 minute dive is Group O. This decays to Group H during the 2 hour 10 minute surface interval.

The actual depth of the second dive is 80 fsw (79 fsw plus a 1 fsw pneumofathometer correction). Table 9-4 is entered at an actual depth of 80 fsw. The Sea Level Equivalent Depth for the second dive is 110 fsw. The residual nitrogen time for Group H at 110 fsw is 27 minutes. The equivalent single dive time therefore is 57 minutes. The appropriate decompression schedule from the Surface Decompression Table Using Oxygen is 110 fsw for 60 minutes. A 26 minute stop at 40 fsw in the chamber is required by the schedule. This stop is taken at a chamber depth of 40 fsw.

Figure 9-25 shows the filled-out Repetitive Dive at Altitude Worksheet for these two dives. Figure 9-26 and Figure 9-27 and shows the filled out Diving Charts for the first and second dives.

9-13 ASCENT TO ALTITUDE AFTER DIVING/FLYING AFTER DIVING.

Leaving the dive site may require temporary ascent to a higher altitude. For example, divers may drive over a mountain pass at higher altitude or leave the dive site by air. Ascent to altitude after diving increases the risk of decompression sickness because of the additional reduction in atmospheric pressure. The higher the altitude, the greater the risk. (Pressurized commercial airline flights are addressed in Note 3 of Table 9-6.)

Table 9-6 gives the surface interval (hours:minutes) required before making a further ascent to altitude. The surface interval depends on the planned increase in altitude and the highest repetitive group designator obtained in the previous 24-hour period. Enter the table with the highest repetitive group designator obtained in the previous 24-hour period. Read the required surface interval from the column for the planned change in altitude.

DIVING AT ALTITUDE WORKSHEET

DATE 10 Jan 99

Actual Dive Site Altitude 7,750 feet

1. Altitude from Table 9-3. 8,000 feet
2. Actual Depth of Dive (corrected per section 9-12.3) 75 + 8 + 1 = 84 fsw
3. Sea Level Equivalent Depth from Table 9-3 120 SLED
4. Repetitive Group from Table 9-4 F
5. Time at Altitude 5 hrs — min
6. New Repetitive Group Designation from Table 9-7 B
7. Residual Nitrogen Time 6 min
8. Planned Bottom Time + 60 min
9. Equivalent Single Dive Time = 66 min
10. Decompression Table

☐ Standard Air Table
☒ Sur D Table Using Oxygen
☐ Unlimited/No-Decompression Table
☐ Sur D Table Using Air

11. Table/Schedule 120 / 70

12. Decompression Schedule

Sea Level Stop Depth	Altitude Stop Depth	Stop Time (Water/Chamber)
10 fsw	fsw	/ min
20 fsw	fsw	/ min
30 fsw	22 fsw	4 / min
40 fsw	fsw	/39 min*
50 fsw	fsw	min
60 fsw	fsw	min

13. Repetitive Group Letter Designation ______

*Chamber stop on SUR D O_2 will be at 40 fsw.

Figure 9-22. Completed Worksheet for Diving at Altitude

DIVING CHART - AIR (1056) *ALTITUDE 8000*

Date: 10 Jan 99

NAME OF DIVER 1: ENCS Payne	DIVING APPARATUS: MK 21	TYPE DRESS: Wet Suit	EGS (PSIG): 2900
NAME OF DIVER 2: BMC Wilson	DIVING APPARATUS: MK 21	TYPE DRESS: Wet Suit	EGS (PSIG): 2900
TENDERS (DIVER 1): SW1 Merkes AND CDR Southerland		TENDERS (DIVER 2): SW1 Norris AND CE1 Menzie	
LEFT SURFACE (LS): 0900	DEPTH (fsw): 75+8+1=(84)/ SLED 120	REACHED BOTTOM (RB): ~~0901~~	DESCENT TIME: :01
LEFT BOTTOM (LB): 1000	TOTAL BOTTOM TIME (TBT): RNT (:60)+:06=:66	TABLE & SCHEDULE USED: 120/:70 Sur 'D' O_2	TIME TO FIRST STOP: 1::46
REACHED SURFACE (RS): 1006::30/ 1055::50	TOTAL DECOMPRESSION TIME (TDT): 55::50	TOTAL TIME OF DIVE (TTD): 01:55::50	REPETITIVE GROUP: N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::44 ↑ 1::20	10			L R	
	3::30 + ::30 = :04; 80 fpm	20			L R	
		22 ~~30~~	:04		L 1005::46 R 1001::46	
	1::46	40		:30 O_2 :05 Air :09 O_2	L R	1054::30 1010::30
75 fpm	30 fpm	50			L R	
		60			L R	
		70			L R	
:01		75 ~~80~~			L 1000 R 0901	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
		130			L R	

PURPOSE OF DIVE: Search	REMARKS: Sur 'D' O_2 OK to Repet
DIVER'S CONDITION: OK	DIVING SUPERVISOR: BUCS (MDV) Daniels

Figure 9-23. Completed Chart for Dive at Altitude.

REPETITIVE
DIVE AT ALTITUDE WORKSHEET

DATE

1. PREVIOUS DIVE

_______ minutes ☐ Standard Air Table ☐ Unlimited/No-Decompression Table

_______ SLED ☐ Sur D Table Using Oxygen ☐ Sur D 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 FOR REPETITIVE DIVE

Altitude from Table 9-3 _______________ feet

Actual Depth of Dive (corrected per section 9-12.3) _______________ fsw

Sea Level Equivalent Depth of repetitive dive from Table 9-3 _______________ SLED

_______ 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

_______ SLED of repetitive dive

_______ minutes, equivalent single dive time from item 4 above

Decompression from (check one):

☐ Standard Air Table ☐ Unlimited/No-Decompression Table

☐ Sur D Table Using Oxygen ☐ Sur D Table Using Air

__________ schedule used (depth/time)

Sea Level Stop Depth:	Altitude Stop Depth	Water Stop Time	Chamber Stop Time
10 fsw	_______ fsw	_______ minutes	_______ minutes
20 fsw	_______ fsw	_______ minutes	_______ minutes
30 fsw	_______ fsw	_______ minutes	_______ minutes
40 fsw	_______ fsw	_______ minutes	_______ minutes*
50 fsw	_______ fsw	_______ minutes	_______ minutes
60 fsw	_______ fsw	_______ minutes	_______ minutes

_______ repetitive group letter designation

*Chamber stop on SUR D O_2 will be at 40 fsw.

Figure 9-24. Completed Worksheet for Repetitive Dive at Altitude.

REPETITIVE DIVE AT ALTITUDE WORKSHEET

DATE 10 Jan 99

1. PREVIOUS DIVE

:60 minutes — [X] Standard Air Table — [ ] Unlimited/No-Decompression Table

120 SLED — [ ] Sur D Table Using Oxygen — [ ] Sur D Table Using Air

O repetitive group letter designation

2. SURFACE INTERVAL

2 hours 10 minutes on surface

O repetitive group from Item 1 above

H new repetitive group letter designation from Residual Nitrogen Timetable

3. RESIDUAL NITROGEN TIME FOR REPETITIVE DIVE

Altitude from Table 9-3 — 8000 feet

Actual Depth of Dive (corrected per section 9-12.3) — 79+1=80 fsw

Sea Level Equivalent Depth of repetitive dive from Table 9-3 — 110 SLED

H new repetitive group letter designation from item 2 above

:27 minutes, (residual nitrogen time from Residual Nitrogen Timetable) or bottom time of previous Sur D dive

4. EQUIVALENT SINGLE DIVE TIME:

:27 minutes, (residual nitrogen time from item 3 above) or bottom time of previous Sur D dive

\+ :30 minutes, actual bottom time of repetitive dive

= :57 minutes, equivalent single dive time

5. DECOMPRESSION FOR REPETITIVE DIVE:

110 SLED of repetitive dive

:57 minutes, equivalent single dive time from item 4 above

Decompression from (check one):

[ ] Standard Air Table — [ ] Unlimited/No-Decompression Table

[X] Sur D Table Using Oxygen — [ ] Sur D Table Using Air

110/60 schedule used (depth/time)

Sea Level Stop Depth:	Altitude Stop Depth	Water Stop Time	Chamber Stop Time
10 fsw	___ fsw	___ minutes	___ minutes
20 fsw	___ fsw	___ minutes	___ minutes
30 fsw	___ fsw	___ minutes	___ minutes
40 fsw	___ fsw	___ minutes	26 minutes*
50 fsw	___ fsw	___ minutes	___ minutes
60 fsw	___ fsw	___ minutes	___ minutes

N/A repetitive group letter designation

*Chamber stop on SUR D O_2 will be at 40 fsw.

Figure 9-25. Completed Worksheet for Repetitve Dive at Altitude.

DIVING CHART - AIR (1112) *ALTITUDE 8000*

NAME OF DIVER 1: ENCS Payne	DIVING APPARATUS: MK 21	TYPE DRESS: Wet Suit	EGS (PSIG): 2900
NAME OF DIVER 2: BMC Wilson	DIVING APPARATUS: MK 21	TYPE DRESS: Wet Suit	EGS (PSIG): 2900
TENDERS (DIVER 1): CDR Morrison AND BMC Carpenter		TENDERS (DIVER 2): BM2 Telitz AND AO1 Beatty	
LEFT SURFACE (LS): 0900	DEPTH (fsw): 82+1=(83) SLED 120	REACHED BOTTOM (RB): ~~0902~~	DESCENT TIME: :02
LEFT BOTTOM (LB): 1000	TOTAL BOTTOM TIME (TBT): :60	TABLE & SCHEDULE USED: 120/60 Std Air	TIME TO FIRST STOP: :02
REACHED SURFACE (RS): 1111::44	TOTAL DECOMPRESSION TIME (TDT): 1:11::44	TOTAL TIME OF DIVE (TTD): 2:11::44	REPETITIVE GROUP: O

Date: 10 Jan 99

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	::14	7 ~~10~~	:45		L 1111::30 R 1026::30	
	::16	15 ~~20~~	:22		L 1026::14 R 1004::14	
	::14	22 ~~30~~	:02		L 1004 R 1002	
	:02	40			L R	
75 fpm	30 fpm	50			L R	
		60			L R	
		70			L R	
		80			L R	
:02		82 ~~90~~			L 1000 R 0902	
		100			L R	
		110			L R	
		120			L R	
		130			L R	

PURPOSE OF DIVE: Search	REMARKS: Std Air OK to Repet
DIVER'S CONDITION: OK	DIVING SUPERVISOR: HTCM (MDV) Phalin

Figure 9-26. Completed Chart for Repetitive Dive at Altitude.

DIVING CHART - AIR (1426) *ALTITUDE 8000*

			Date 10 Jan 99
NAME OF DIVER 1 ENCS Payne	DIVING APPARATUS MK 21	TYPE DRESS Wet Suit	EGS (PSIG) 2825
NAME OF DIVER 2 BMC Wilson	DIVING APPARATUS MK 21	TYPE DRESS Wet Suit	EGS (PSIG) 2825
TENDERS (DIVER 1) BU1 Doyle AND UT2 Stacy		TENDERS (DIVER 2) SW2 Brooks AND BU2 McElroy	
LEFT SURFACE (LS) 1322	DEPTH (fsw) 79+1=(80) / SLED 110	REACHED BOTTOM (RB) ~~1324~~	DESCENT TIME :02
LEFT BOTTOM (LB) 1352	TOTAL BOTTOM TIME (TBT) RNT (:30)+:27=:57	TABLE & SCHEDULE USED 110/60 Sur 'D' O_2	TIME TO FIRST STOP :02::38
REACHED SURFACE (RS) 1354::38/1425::58	TOTAL DECOMPRESSION TIME (TDT) :33::58	TOTAL TIME OF DIVE (TTD) 1:03:58	REPETITIVE GROUP N/A

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME WATER	DECOMPRESSION TIME CHAMBER	TIME WATER	TIME CHAMBER
	:02::38 / :01::20	10			L R	
	:03+::30=:04 / 80 fpm	20			L R	
		30			L R	
		40		:26	L R	1424::38 1358::38
75 fpm	30 fpm	50			L R	
		60			L R	
		70			L R	
:02		79 ~~80~~			L 1352 R 1324	
		90			L R	
		100			L R	
		110			L R	
		120			L R	
		130			L R	

PURPOSE OF DIVE Search	REMARKS Sur 'D' O_2 OK to Repet
DIVER'S CONDITION OK	DIVING SUPERVISOR MDV Deen

Figure 9-27. Completed Chart for Repetitive Dive at Altitude.

Table 9-6. *Required Surface Interval Before Ascent to Altitude After Diving.*

Repetitive Group Designator	**Increase in Altitude**									
	1000	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**	**10000**
A	0:00	0:00	0:00	0:00	0:00	0:00	0:00	**0:00**	0:00	0:00
B	0:00	0:00	0:00	0:00	0:00	0:00	0:00	**0:00**	0:00	2:11
C	0:00	0:00	0:00	0:00	0:00	0:00	0:00	**0:00**	3:06	8:26
D	0:00	0:00	0:00	0:00	0:00	0:00	0:09	**3:28**	7:33	12:52
E	0:00	0:00	0:00	0:00	0:00	0:51	3:35	**6:54**	10:59	16:18
F	0:00	0:00	0:00	0:00	1:12	3:40	6:23	**9:43**	13:47	19:07
G	0:00	0:00	0:00	1:23	3:34	6:02	8:46	**12:05**	16:10	21:29
H	0:00	0:00	1:31	3:26	5:37	8:05	10:49	**14:09**	18:13	23:33
I	0:00	1:32	3:20	5:15	7:26	9:54	12:38	**15:58**	20:02	24:00
J	1:32	3:09	4:57	6:52	9:04	11:32	14:16	**17:35**	21:39	24:00
K	3:00	4:37	6:25	8:20	10:32	13:00	15:44	**19:03**	23:07	24:00
L	4:21	5:57	7:46	9:41	11:52	14:20	17:04	**20:23**	24:00	24:00
M	5:35	7:11	9:00	10:55	13:06	15:34	18:18	**21:37**	24:00	24:00
N	6:43	8:20	10:08	12:03	14:14	16:42	19:26	**22:46**	24:00	24:00
O	7:47	9:24	11:12	13:07	15:18	17:46	20:30	**23:49**	24:00	24:00
Z	8:17	9:54	11:42	13:37	15:49	18:17	21:01	**24:00**	24:00	24:00
Exceptional Exposure	Wait 48 hours before flying									

NOTE 1 When using Table 9-6, use the highest repetitive group designator obtained in the previous 24-hour period.

NOTE 2 Table 9-6 may only be used when the maximum altitude achieved is 10,000 feet or less. For ascents above 10,000 feet, consult NAVSEA 00C for guidance.

NOTE 3 The cabin pressure in commercial aircraft is maintained at a constant value regardless of the actual altitude of the flight. Though cabin pressure varies somewhat with aircraft type, the nominal value is 8,000 feet. For commercial flights, use a final altitude of 8000 feet to compute the required surface interval before flying.

NOTE 4 No surface interval is required before taking a commercial flight if the dive site is at 8000 feet or higher. In this case, flying results in an increase in atmospheric pressure rather than a decrease.

NOTE 5 No repetitive group is given for air dives with surface decompression on oxygen or air. For these surface decompression dives, enter the standard air table with the sea level equivalent depth and bottom time of the dive to obtain the appropriate repetitive group designator to be used.

NOTE 6 For ascent to altitude following a non-staturation helium-oxygen dive, wait 12 hours if the dive was a no-decompression dive. Wait 24 hours if the dive was a decompression dive.

Table 9-7. *Unlimited/No-Decompression Limits and Repetitive Group Designation Table for Unlimited/No-Decompression Air Dives.*

Depth (feet)	Depth (meters)	No-Decompression Limits (min)	Group Designation A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10	3.1	unlimited	60	120	210	300	797	*									
15	4.6	unlimited	35	70	110	160	225	350	452	*							
20	6.1	unlimited	25	50	75	100	135	180	240	325	390	917	*				
25	7.7	595	20	35	55	75	100	125	160	195	245	315	361	540	595		
30	9.2	405	15	30	45	60	75	95	120	145	170	205	250	310	344	405	
35	10.7	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270	310
40	12.3	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200	
50	15.3	100		10	15	25	30	40	50	60	70	80	90	100			
60	18.4	60		10	15	20	25	30	40	50	55	60					
70	21.5	50		5	10	15	20	30	35	40	45	50					
80	24.5	40		5	10	15	20	25	30	35	40						
90	27.6	30		5	10	12	15	20	25	30							
100	30.6	25		5	7	10	15	20	22	25							
110	33.7	20			5	10	13	15	20								
120	36.8	15			5	10	12	15									
130	39.8	10			5	8	10										
140	42.9	10			5	7	10										
150	46.0	5			5												
160	49.0	5				5											
170	52.1	5				5											
180	55.2	5				5											
190	58.2	5				5											

* Highest repetitive group that can be achieved at this depth regardless of bottom time.

Table 9-8. 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 that 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 Nitrogen Time is given, then the repetitive group does not change.

Repetitive group at the beginning of the surface interval

Repetitive group at the beginning of the surface interval	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	1:36 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 Repetitive Group Designation

Repetitive Dive Depth feet	meters	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
10	3.1	**	**	**	**	**	**	**	**	**	**	**	797	279	159	88	39
20	6.1	**	**	**	**	**	**	917	399	279	208	159	120	88	62	39	18
30	9.2	†	†	†	349	279	229	190	159	132	109	88	70	54	39	25	12
40	12.3	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	15.3	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
60	18.4	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	21.5	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	24.5	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	27.6	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	3
100	30.6	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	33.7	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	36.8	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3
130	39.8	46	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3
140	42.9	42	40	38	35	32	29	26	23	20	18	15	12	10	7	5	2
150	46.0	40	38	35	32	30	27	24	22	19	17	14	12	9	7	5	2
160	49.0	37	36	33	31	28	26	23	20	18	16	13	11	9	6	4	2
170	52.1	35	34	31	29	26	24	22	19	17	15	12	10	8	6	4	2
180	55.2	32	31	29	27	25	22	20	18	16	14	11	10	8	6	4	2
190	58.2	31	30	28	26	24	21	19	17	15	13	10	10	8	6	4	2

Residual Nitrogen Times (MInutes)

† Read vertically downward to the 40/12.3 (feet/meter) repetitive dive depth. Use the corresponding residual nitrogen times (minutes) to compute the equivalent single dive time. Decompress using the 40/12.3 (feet/meter) standard air decompression table.

Example: A diver surfaces from a 60 fsw for 60 minutes no-decompression dive at sea level in Repetitive Group J. After a surface interval of 6 hours 10 minutes, the diver makes a second dive to 30 fsw for 20 minutes placing him in Repetitive Group C. He plans to fly home in a commercial aircraft in which the cabin pressure is controlled at 8000 feet. What is the required surface interval before flying?

The planned increase in altitude is 8000 feet. Because the diver has made two dives in the previous 24-hour period, you must use the highest Repetitive Group Designator of the two dives. Enter Table 9-6 at 8000 feet and read down to Repetitive Group J. The diver must wait 17 hours and 35 minutes after completion of the second dive before flying.

Example: Upon completion of a dive at an altitude of 4000 feet, the diver plans to ascend to 7500 feet in order to cross a mountain pass. The diver's repetitive group upon surfacing is Group G. What is the required surface interval before crossing the pass?

The planned increase in altitude is 3500 feet. Enter Table 9-6 at 4000 feet and read down to Repetitive Group G. The diver must delay 1 hour and 23 minutes before crossing the pass.

Example: Upon completion of a dive at 2000 feet, the diver plans to fly home in an unpressurized aircraft at 5000 feet. The diver's repetitive group designator upon surfacing is Group K. What is the required surface interval before flying?

The planned increase in altitude is 3000 feet. Enter Table 9-6 at 3000 feet and read down to Repetitive Group K. The diver must delay 6 hours and 25 minutes before taking the flight.

Table 9-9. *U.S. Navy Standard Air Decompression Table.*

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters)					Total decompression time (min:sec)	Repetitive group
			50 15.3	40 12.3	30 9.2	20 6.1	10 3.1		
40 12.3	200						0	1:20	*
	210	1:00					2	3:20	N
	230	1:00					7	8:20	N
	250	1:00					11	12:20	O
	270	1:00					15	16:20	O
	300	1:00					19	20:20	Z
	Exceptional Exposure								
	360	1:00					23	24:20	**
	480	1:00					41	42:20	**
	720	1:00					69	70:20	**
50 15.3	100						0	1:40	*
	110	1:20					3	4:40	L
	120	1:20					5	6:40	M
	140	1:20					10	11:40	M
	160	1:20					21	22:40	N
	180	1:20					29	30:40	O
	200	1:20					35	36:40	O
	220	1:20					40	41:40	Z
	240	1:20					47	48:40	Z
60 18.4	60						0	2:00	*
	70	1:40					2	4:00	K
	80	1:40					7	9:00	L
	100	1:40					14	16:00	M
	120	1:40					26	28:00	N
	140	1:40					39	41:00	O
	160	1:40					48	50:00	Z
	180	1:40					56	58:00	Z
	200	1:20				1	69	72:00	Z
	Exceptional Exposure								
	240	1:20				2	79	83:00	**
	360	1:20				20	119	141:00	**
	480	1:20				44	148	194:00	**
	720	1:20				78	187	267:00	**
70 21.5	50						0	2:20	*
	60	2:00					8	10:20	K
	70	2:00					14	16:20	L
	80	2:00					18	20:20	M
	90	2:00					23	25:20	N
	100	2:00					33	35:20	N
	110	1:40				2	41	45:20	O
	120	1:40				4	47	53:20	O
	130	1:40				6	52	60:20	O
	140	1:40				8	56	66:20	Z
	150	1:40				9	61	72:20	Z
	160	1:40				13	72	87:20	Z
	170	1:40				19	79	100:20	Z

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 9-9. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)	Repetitive group
80 / 24.5	40						0	2:40	*
	50	2:20					10	12:40	K
	60	2:20					17	19:40	L
	70	2:20					23	25:40	M
	80	2:00				2	31	35:40	N
	90	2:00				7	39	48:40	N
	100	2:00				11	46	59:40	O
	110	2:00				13	53	68:40	O
	120	2:00				17	56	75:40	Z
	130	2:00				19	63	83:40	Z
	140	2:00				26	69	97:40	Z
	150	2:00				32	77	111:40	Z
	Exceptional Exposure								
	180	2:00				35	85	122:40	**
	240	1:40			6	52	120	180:40	**
	360	1:40			29	90	160	281:40	**
	480	1:40			59	107	187	355:40	**
	720	1:20		17	108	142	187	456:40	**
90 / 27.6	30						0	3:00	*
	40	2:40					7	10:00	J
	50	2:40					18	21:00	L
	60	2:40					25	28:00	M
	70	2:20				7	30	40:00	N
	80	2:20				13	40	56:00	N
	90	2:20				18	48	69:00	O
	100	2:20				21	54	78:00	Z
	110	2:20				24	61	88:00	Z
	120	2:20				32	68	103:00	Z
	130	2:00			5	36	74	118:00	Z
100 / 30.6	25						0	3:20	*
	30	3:00					3	6:20	I
	40	3:00					15	18:20	K
	50	2:40				2	24	29:20	L
	60	2:40				9	28	40:20	N
	70	2:40				17	39	59:20	O
	80	2:40				23	48	74:20	O
	90	2:20			3	23	57	86:20	Z
	100	2:20			7	23	66	99:20	Z
	110	2:20			10	34	72	119:20	Z
	120	2:20			12	41	78	134:20	Z
	Exceptional Exposure								
	180	2:00		1	29	53	118	204:20	**
	240	2:00		14	42	84	142	285:20	**
	360	1:40	2	42	73	111	187	418:20	**
	480	1:40	21	61	91	142	187	505:20	**
	720	1:40	55	106	122	142	187	615:20	**

* See No Decompression Table for repetitive groups

** Repetitive dives may not follow exceptional exposure dives

Table 9-9. *U.S. Navy Standard Air Decompression Table (Continued).*

Depth feet/meters: 110 / 33.7

Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)	Repetitive group
20						0	3:40	*
25	3:20					3	6:40	H
30	3:20					7	10:40	J
40	3:00				2	21	26:40	L
50	3:00				8	26	37:40	M
60	3:00				18	36	57:40	N
70	2:40			1	23	48	75:40	O
80	2:40			7	23	57	90:40	Z
90	2:40			12	30	64	109:40	Z
100	2:40			15	37	72	127:40	Z

Depth feet/meters: 120 / 36.8

Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)	Repetitive group
15								0	4:00	*
20	3:40							2	6:00	H
25	3:40							6	10:00	I
30	3:40							14	18:00	J
40	3:20						5	25	34:00	L
50	3:20						15	31	50:00	N
60	3:00					2	22	45	73:00	O
70	3:00					9	23	55	91:00	O
80	3:00					15	27	63	109:00	Z
90	3:00					19	37	74	134:00	Z
100	3:00					23	45	80	152:00	Z
Exceptional Exposure										
120	2:40				10	19	47	98	178:00	**
180	2:20			5	27	37	76	137	286:00	**
240	2:20			23	35	60	97	179	398:00	**
360	2:00		18	45	64	93	142	187	553:00	**
480	1:40	3	41	64	93	122	142	187	656:00	**
720	1:40	32	74	100	114	122	142	187	775:00	**

Depth feet/meters: 130 / 39.8

Bottom time (min)	Time first stop (min:sec)	70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)	Repetitive group
10								0	4:20	*
15	4:00							1	5:20	F
20	4:00							4	8:20	H
25	4:00							10	14:20	J
30	3:40						3	18	25:20	M
40	3:40						10	25	39:20	N
50	3:20					3	21	37	65:20	O
60	3:20					9	23	52	88:20	Z
70	3:20					16	24	61	105:20	Z
80	3:00				3	19	35	72	133:20	Z
90	3:00				8	19	45	80	156:20	Z

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 9-9. *U.S. Navy Standard Air Decompression Table (Continued).*

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 90 27.6	80 24.5	70 21.5	60 18.4	50 15.3	40 12.3	30 9.2	20 6.1	10 3.1	Total decompression time (min:sec)	Repetitive group
140 42.9	10										0	4:40	*
	15	4:20									2	6:40	G
	20	4:20									6	10:40	I
	25	4:00								2	14	20:40	J
	30	4:00								5	21	30:40	K
	40	3:40							2	16	26	48:40	N
	50	3:40							6	24	44	78:40	O
	60	3:40							16	23	56	99:40	Z
	70	3:20						4	19	32	68	127:40	Z
	80	3:20						10	23	41	79	157:40	Z
	Exceptional Exposure												
	90	3:00					2	14	18	42	88	168:40	**
	120	3:00					12	14	36	56	120	242:40	**
	180	2:40				10	26	32	54	94	168	388:40	**
	240	2:20			8	28	34	50	78	124	187	513:40	**
	360	2:00		9	32	42	64	84	122	142	187	686:40	**
	480	2:00		31	44	59	100	114	122	142	187	803:40	**
	720	1:40	16	56	88	97	100	114	122	142	187	926:40	**
150 46.0	5										0	5:00	C
	10	4:40									1	6:00	E
	15	4:40									3	8:00	G
	20	4:20								2	7	14:00	H
	25	4:20								4	17	26:00	K
	30	4:20								8	24	37:00	L
	40	4:00							5	19	33	62:00	N
	50	4:00							12	23	51	91:00	O
	60	3:40						3	19	26	62	115:00	Z
	70	3:40						11	19	39	75	149:00	Z
	80	3:20					1	17	19	50	84	176:00	Z
160 49.0	5										0	5:20	D
	10	5:00									1	6:20	F
	15	4:40								1	4	10:20	H
	20	4:40								3	11	19:20	J
	25	4:40								7	20	32:20	K
	30	4:20							2	11	25	43:20	M
	40	4:20							7	23	39	74:20	N
	50	4:00						2	16	23	55	101:20	Z
	60	4:00						9	19	33	69	135:20	Z
	Exceptional Exposure												
	70	3:40					1	17	22	44	80	169:20	**

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 9-9. *U.S. Navy Standard Air Decompression Table (Continued).*

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 110 / 33.7	100 / 30.6	90 / 27.6	80 / 24.5	70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)	Repetitive group
170 / 52.1	5												0	5:40	D
	10	5:20											2	7:40	F
	15	5:00										2	5	12:40	H
	20	5:00										4	15	24:40	J
	25	4:40									2	7	23	37:40	L
	30	4:40									4	13	26	48:40	M
	40	4:20								1	10	23	45	84:40	O
	50	4:20								5	18	23	61	112:40	Z
	60	4:00							2	15	22	37	74	155:40	Z
	Exceptional Exposure														
	70	4:00							8	17	19	51	86	186:40	**
	90	3:40						12	12	14	34	52	120	249:40	**
	120	3:00				2	10	12	18	32	42	82	156	359:40	**
	180	2:40			4	10	22	28	34	50	78	120	187	538:40	**
	240	2:40			18	24	30	42	50	70	116	142	187	684:40	**
	360	2:20		22	34	40	52	60	98	114	122	142	187	876:40	**
	480	2:00	14	40	42	56	91	97	100	114	122	142	187	1010:40	**
180 / 55.2	5												0	6:00	D
	10	5:40											3	9:00	F
	15	5:20										3	6	15:00	I
	20	5:00									1	5	17	29:00	J
	25	5:00									3	10	24	43:00	L
	30	5:00									6	17	27	56:00	N
	40	4:40								3	14	23	50	96:00	O
	50	4:20							2	9	19	30	65	131:00	Z
	60	4:20							5	16	19	44	81	171:00	Z
190 / 58.2	5	5:40											0	6:20	D
	10	5:40										1	3	10:20	G
	15	5:40										6	7	17:20	I
	20	5:20									2	6	20	34:20	K
	25	:5:20									5	11	25	47:20	M
	30	5:00								1	8	19	32	66:20	N
	40	5:00								8	14	23	55	106:20	O
	Exceptional Exposure														
	50	4:40							4	13	22	33	72	150:20	**
	60	4:40							10	17	19	50	84	186:20	**

* See No Decompression Table for repetitive groups
** Repetitive dives may not follow exceptional exposure dives

Table 9-9. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 130 / 39.8	120 / 36.8	110 / 33.7	100 / 30.6	90 / 27.6	80 / 24.5	70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)
200 / 61.3	Exceptional Exposure															
	5	6:20													1	7:40
	10	6:00												1	4	11:40
	15	5:40											1	4	10	21:40
	20	5:40											3	7	27	43:40
	25	5:40											7	14	25	52:40
	30	5:20										2	9	22	37	76:40
	40	5:00									2	8	17	23	59	115:40
	50	5:00									6	16	22	39	75	164:40
	60	4:40								2	13	17	24	51	89	202:40
	90	3:40					1	10	10	12	12	30	38	74	134	327:40
	120	3:20				6	10	10	10	24	28	40	64	98	180	476:40
	180	2:40		1	10	10	18	24	24	42	48	70	106	142	187	688:40
	240	2:40		6	20	24	24	36	42	54	68	114	122	142	187	845::40
	360	2:20	12	22	36	40	44	56	82	98	100	114	122	142	187	1061:40
210 / 64.4	Exceptional Exposure															
	5	6:40													1	8:00
	10	6:20												2	4	13:00
	15	6:00											1	5	13	26:00
	20	6:00											4	10	23	44:00
	25	5:40										2	7	17	27	60:00
	30	5:40										4	9	24	41	85:00
	40	5:20									4	9	19	26	63	128:00
	50	5:20								1	9	17	19	45	80	178:00
220 / 67.4	Exceptional Exposure															
	5	7:00													1	8:20
	10	6:40												2	5	14:20
	15	6:20											2	5	16	30:20
	20	6:00										1	3	11	24	46:20
	25	6:00										3	8	19	33	70:20
	30	5:40									1	7	10	23	47	95:20
	40	5:40									6	12	22	29	68	144:20
	50	5:20								3	12	17	18	51	86	194:20
230 / 70.5	Exceptional Exposure															
	5	7:20													2	9:40
	10	6:20											1	2	6	16:40
	15	6:20											3	6	18	34:40
	20	6:20										2	5	12	26	52:40
	25	6:20										4	8	22	37	78:40
	30	6:00									2	8	12	23	51	103:40
	40	5:40								1	7	15	22	34	74	160:40
	50	5:40								5	14	16	24	51	89	206:40

Table 9-9. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 130 / 39.8	120 / 36.8	110 / 33.7	100 / 30.6	90 / 27.6	80 / 24.5	70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)
240 / 73.5	Exceptional Exposure															
	5	7:40													2	10:00
	10	7:00											1	3	6	18:00
	15	7:00											4	6	21	39:00
	20	6:40										3	6	15	25	57:00
	25	6:20									1	4	9	24	40	86:00
	30	6:20									4	8	15	22	56	113:00
	40	6:00								3	7	17	22	39	75	171:00
	50	5:40							1	8	15	16	29	51	94	222:00

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 200 / 61.3	190 / 58.2	180 / 55.2	170 / 52.1	160 / 49.0	150 / 46.0	140 / 42.9	130 / 39.8	120 / 36.8	110 / 33.7	100 / 30.6	90 / 27.6	80 / 24.5	70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decompression time (min:sec)
250 / 76.6	Exceptional Exposure																						
	5	7:40																			1	2	11:20
	10	7:20																		1	4	7	20:20
	15	7:00																	1	4	7	22	42:20
	20	7:00																	4	7	17	27	63:20
	25	6:40																2	7	10	24	45	96:20
	30	6:40																6	7	17	23	59	120:20
	40	6:20															5	9	17	19	45	79	182:20
	60	5:20												4	10	10	10	12	22	36	64	164	302:20
	90	4:20									8	10	10	10	10	10	28	28	44	68	98	186	518:20
	120	3:40							5	10	10	10	10	16	24	24	36	48	64	94	142	187	688:20
	180	3:00					4	8	8	10	22	24	24	32	42	44	60	84	114	122	142	187	935:20
	240	3:00					9	14	21	22	22	40	40	42	56	76	98	100	114	122	142	187	1113:20
260 / 79.7	Exceptional Exposure																						
	5	8:00																			1	2	11:40
	10	7:40																		2	4	9	23:40
	15	7:20																	2	4	10	22	46:40
	20	7:00																1	4	7	20	31	71:40
	25	7:00																3	8	11	23	50	103:40
	30	6:40															2	6	8	19	26	61	130:40
	40	6:20														1	6	11	16	19	49	84	194:40
270 / 82.7	Exceptional Exposure																						
	5	8:20																			1	3	13:00
	10	8:00																		2	5	11	27:00
	15	7:40																	3	4	11	24	51:00
	20	7:20																2	3	9	21	35	79:00
	25	7:00															2	3	8	13	23	53	111:00
	30	7:00															3	6	12	22	27	64	143:00
	40	6:40														5	6	11	17	22	51	88	209:00

Table 9-9. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 200 / 61.3	190 / 58.2	180 / 55.2	170 / 52.1	160 / 49.0	150 / 46.0	140 / 42.9	130 / 39.8	120 / 36.8	110 / 33.7	100 / 30.6	90 / 27.6	80 / 24.5	70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decom-pression time (min:sec)
280 / 85.8	Exceptional Exposure																						
	5	8:40																			2	2	13:20
	10	8:00																	1	2	5	13	30:20
	15	7:40																1	3	4	11	26	54:20
	20	7:40																3	4	8	23	39	86:20
	25	7:20															2	5	7	16	23	56	118:20
	30	7:00														1	3	7	13	22	30	70	155:20
	40	6:40													1	6	6	13	17	27	51	93	223:20
290 / 88.9	Exceptional Exposure																						
	5	9:00																			2	3	14:40
	10	8:20																	1	3	5	16	34:40
	15	8:00																1	3	6	12	26	57:40
	20	8:00																3	7	9	23	43	94:40
	25	7:40															3	5	8	17	23	60	125:40
	30	7:20														1	5	6	16	22	36	72	167:40
	40	7:00													3	5	7	15	16	32	51	95	233:40

Depth feet/meters	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 200 / 61.3	190 / 58.2	180 / 55.2	170 / 52.1	160 / 49.0	150 / 46.0	140 / 42.9	130 / 39.8	120 / 36.8	110 / 33.7	100 / 30.6	90 / 27.6	80 / 24.5	70 / 21.5	60 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Total decom-pression time (min:sec)
300 / 91.9	Exceptional Exposure																						
	5	9:20																			3	3	16:00
	10	8:40																	1	3	6	17	37:00
	15	8:20																2	3	6	15	26	62:00
	20	8:00															2	3	7	10	23	47	102:00
	25	7:40														1	3	6	8	19	26	61	134:00
	30	7:40														2	5	7	17	22	39	75	177:00
	40	7:20													4	6	9	15	17	34	51	90	‘236:00
	60	6:00									4	10	10	10	10	10	14	28	32	50	90	187	465:00
	90	4:40					‘3	8	8	10	10	10	10	16	24	24	34	48	64	90	142	187	698:00
	120	4:00			4	8	8	8	8	10	14	24	24	24	34	42	58	66	102	122	142	187	895:00
	180	3:30	6	8	8	8	14	20	21	21	28	40	40	48	56	82	98	100	114	122	142	187	1173:00

Table 9-10. 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 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	Surface Interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompression time (min:sec)
70 / 21.5	50	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	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 / 24.5	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 / 27.6	30	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 / 30.6	25	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 / 33.7	20	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 9-10. 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 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	Surface Interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompression time (min:sec)
120 / 36.8	15	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	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			3	7		51		75:20
	100	3:00			6	15		54		89:20
130 / 39.8	10	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 / 42.9	10	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 / 46.0	5	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

Table 9-10. 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 / 18.4	50 / 15.3	40 / 12.3	30 / 9.2	Surface Interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompression time (min:sec)
160 / 49.0	5	5:20					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	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		46:40
	40	3:40		3	5	8		32		63:40
	45	3:20	3	4	8	6		38		74:40
170 / 52.1	5	5:40								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 9-11.__ 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 / 9.2	20 / 6.1	10 / 3.1	Surface Interval	Chamber stops (air) (min) (feet/meters) 20 / 6.1	10 / 3.1	Total decompression time (min:sec)
40 12.3	230	1:00			3			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 15.3	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 18.4	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 21.5	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 24.5	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 9-11. 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 / 9.2	20 / 6.1	10 / 3.1	Surface Interval	Chamber stops (air) (min) (feet/meters) 20 / 6.1	10 / 3.1	Total decompression time (min:sec)
90 / 27.6	40	2:40			3			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 / 30.6	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 / 33.7	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
120 / 36.8	25	3:40			3			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

Table 9-11. 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 / 15.3	40 / 12.3	30 / 9.2	20 / 6.1	10 / 3.1	Surface Interval	Chamber stops (air) (min) (feet/meters) 20 / 6.1	10 / 3.1	Total decompression time (min:sec)
130 / 39.8	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 / 42.9	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 / 46.0	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 / 49.0	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
170 / 52.1	15	5:00				3			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

Table 9-11. 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)					Surface Interval	Chamber stops (air) (min) (feet/meters)		Total decompression time (min:sec)
			50 15.3	40 12.3	30 9.2	20 6.1	10 3.1		20 6.1	10 3.1	
180 55.2	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 58.2	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

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CHAPTER 10

Nitrogen-Oxygen Diving Operations

10-1 INTRODUCTION

Nitrogen-oxygen (NITROX) diving is a unique type of diving using nitrogen-oxygen breathing gas mixtures ranging from 75 percent nitrogen/25 percent oxygen to 60 percent nitrogen/40 percent oxygen. Using NITROX significantly increases the amount of time a diver can spend at depth without decompressing. It also decreases the required decompression time compared to a similar dive made to the same depth using air. NITROX may be used in all diving operations suitable for air, but its use is limited to a normal depth of 140 fsw.

NITROX breathing gas mixtures are normally used for shallow dives. The most benefit is gained when NITROX is used shallower than 50 fsw, but it can be advantageous when used to a depth of 140 fsw.

10-1.1 Advantages and Disadvantages of NITROX Diving. The advantages of using NITROX rather than air for diving include:

- Extended bottom times for no-decompression diving.
- Reduced decompression time.
- Reduced residual nitrogen in the body after a dive.
- Reduced possibility of decompression sickness.
- Reduced Nitrogen Narcosis

The disadvantages of using NITROX include:

- Increased risk of CNS oxygen toxicity.
- Producing NITROX mixtures requires special equipment.
- NITROX equipment requires special cleaning techniques.
- Long-duration NITROX dives can result in pulmonary oxygen toxicity.
- Working with NITROX systems requires special training.
- NITROX is expensive to purchase.

10-2 EQUIVALENT AIR DEPTH

The partial pressure of nitrogen in a NITROX mixture is the key factor determining the diver's decompression obligation. Oxygen plays no role. The decompression obligation for a NITROX dive therefore can be determined using the Standard Air Tables simply by selecting the depth on air that has the same partial pressure of nitrogen as the NITROX mixture. This depth is called the Equivalent Air Depth (EAD). For example, the nitrogen partial pressure in a 68% nitrogen 32% oxygen mixture at 63 fsw is 2.0 ata. This is the same partial pressure of nitrogen found in air at 50 fsw. 50 fsw is the Equivalent Air Depth.

10-2.1 Equivalent Air Depth Calculation.

The Equivalent Air Depth can be computed from the following formula:

$$EAD = \frac{(1 - O_2\%)\ (D + 33)}{0.79} - 33$$

Where:

EAD = equivalent depth on air (fsw)
D = diving depth on mixture (fsw)
$O_2\%$ = oxygen concentration in breathing medium (percentage decimal)

For example, while breathing a mixture containing 40 percent oxygen ($O_2\%$ = 0.40) at 70 fsw (D = 70), the equivalent air depth would be:

$$EAD = \frac{(1 - 0.40)\ (70 + 33)}{0.79} - 33$$

$$= \frac{(0.60)\ (103)}{0.79} - 33$$

$$= \frac{61.8}{0.79} - 33$$

$$= 78.22 - 33$$

$$= \mathbf{45.2\ fsw}$$

Note that with NITROX, the Equivalent Air Depth is always shallower than the diver’s acual depth. This is the reason that NITROX offers a decompression advantage over air.

10-3 OXYGEN TOXICITY

Although the use of NITROX can increase the diver’s bottom time and reduce the risk of nitrogen narcosis, using a NITROX mixture raises the concern for oxygen toxicity. For example, using air as the breathing medium, an oxygen partial pressure (ppO_2) of 1.6 ata is reached at a depth of 218 fsw. In contrast, when using the NITROX mixture containing 60 percent nitrogen and 40 percent oxygen, a ppO_2 of 1.6 ata is reached at 99 fsw. Therefore, oxygen toxicity must be considered when diving a NITROX mixture and is a limiting factor when considering depth and duration of a NITROX dive.

Generally speaking, there are two types of oxygen toxicity—central nervous system (CNS) oxygen and pulmonary oxygen toxicity. CNS oxygen toxicity is usually not encountered unless the partial pressure of oxygen approaches or exceeds 1.6 ata, but it can result in serious symptoms including potentially life-threatening convulsions. Pulmonary oxygen toxicity may result from conducting long-duration dives at oxygen partial pressures in excess of 1.0 ata. For example, a dive longer than 240 minutes at 1.3 ata or a dive longer than 320 minutes at 1.1 ata may place the diver at risk if the exposure is on a daily basis. Pulmonary oxygen toxicity under these conditions can result in decrements of pulmonary function, but is not life threatening.

The NITROX Equivalent Air Depth (EAD) Decompression Selection Table (Table 10-1) was developed considering both CNS and pulmonary oxygen toxicity. Normal working dives that exceed a ppO_2 of 1.4 ata are not permitted, principally to avoid the risk of CNS oxygen toxicity. Dives with a ppO_2 less than 1.4 ata, however, can be conducted using the full range of bottom times allowed by the air tables without concern for CNS or pulmonary oxygen toxicity.

Supervisors must keep in mind that pulmonary oxygen toxicity may become an issue with frequent, repetitive diving. The effects of pulmonary oxygen toxicity can be cumulative and can reduce the underwater work performance of susceptible individuals after a long series of repetitive daily exposures. Fatigue, headache, flu-like symptoms, and numbness of the fingers and toes may also be experienced with repetitive exposures. Table 10-1 takes these repetitive exposures into account, and therefore problems with oxygen toxicity should not be encountered with its use. If symptoms are experienced, the diver should stop diving NITROX until they resolve.

10-3.1 **Selecting the Proper NITROX Mixture.** Considerable caution must be used when selecting the proper NITROX mixture for a dive. The maximum depth of the dive must be known as well as the planned bottom time. Once the maximum depth is known, the various NITROX mixtures can be evaluated to determine which one will provide the least amount of decompression while also allowing for a maximum bottom time. If a diver's depth exceeds that allowed for a certain NITROX mixture, the diver is at great risk of life-threatening oxygen toxicity.

10-4 NITROX DIVING PROCEDURES

10-4.1 **NITROX Diving Using Equivalent Air Depths.** NITROX diving is based upon the current U.S. Navy Air Decompression Tables. The actual schedule used is adjusted for the oxygen percentage in the breathing gas. To use the EAD Decompression Selection Table (Table 10-1), find the actual oxygen percentage of the breathing gas in the heading and the diver's actual depth in the left column to determine the appropriate schedule to be used from the U.S. Navy Air Decompression Tables. The EAD decompression schedule is where the column and row intersect. Dives using NITROX may be used with any schedule from the U.S. Navy Air Decompression Tables (No-Decompression Limits for Air, Standard Air Decompression, Surface Decompression using Air or Surface Decompression Using Oxygen). When using Table 10-1, round all gas mixtures using the standard rounding rule where gas mixes at or above 0.5% round up to the next whole percent and mixes of 0.1% to 0.4% round down to the next whole percent. Once an EAD is determined and a Navy air table is selected, follow the rules of the Navy air table using the EAD for the remainder of the dive.

Table 10-1. *Equivalent Air Depth Table.*

Diver's Actual Depth (fsw)	EAD Feet															
	25% O_2	26% O_2	27% O_2	28% O_2	29% O_2	30% O_2	31% O_2	32% O_2	33% O_2	34% O_2	35% O_2	36% O_2	37% O_2	38% O_2	39% O_2	40% O_2
20	20	20	20	20	20	20	20	15	15	15	15	15	10	10	10	10
30	30	30	30	30	30	30	30	25	25	25	20	20	20	20	20	20
40	40	40	40	40	40	40	40	35	30	30	30	30	30	30	25	25
50	50	50	50	50	50	50	50	40	40	40	40	40	35	35	35	35
60	60	60	60	60	60	60	50	50	50	50	50	50	50	50	40	40
70	70	70	70	70	70	60	60	60	60	60	60	60	50	50	50	50
80	80	80	80	80	70	70	70	70	70	70	70	60	60	60	60	60
90	90	90	90	90	80	80	80	80	80	80	70	70	70 (:107)	70 (:80)	70 (:61)	70 (:47)
100	100	100	100	90	90	90	90	90	90	80 (:113)	80 (:82)	80 (:61)	80 (:46)	80 (:36)	80 (:29)	70 (:23)
110	110	110	110	100	100	100	100	100 (:96)	100 (:69)	90 (:51)	90 (:39)	90 (:30)				
120	120	120	120	110	110	110 (:91)	110 (:64)	110 (:47)	100 (:35)	100 (:27)						
130	130	130	120	120 (:95)	120 (:65)	120 (:47)	120 (:35)	110 (:26)								
140	140	140 (:109)	130 (:73)	130 (:50)	130 (:36)											
150	150 (:89)	150 (:59)	140 (:41)													
160	160 (:50)	160 (:35)														

EAD = Equivalent Air Depth - For Decompression Table Selection Only Rounded to Next Greater Depth

(thick line) = 1.4 ata Normal working limit.

(shaded box) = Depth exceeds the normal working limit, requires the Commanding Officer's authoration and surface-supplied equipment. Repetitive dives are not authorized. Times listed in parentheses indicate maximum allowable exposure.

Note[1]: **Depths not listed are considered beyond the safe limits of NITROX diving**.

Note[2]: The EAD, 1.4 ata Normal Working Limit Line and Maximum Allowable Exposure Time for dives deeper than the Normal Working Limit Line are calculated assuming the diver rounds the oxygen percentage in the gas mixture using the standard rounding rule discussed in paragraph 10-4.1. The calculations also take into account the allowable ± 0.5 percent error in gas analysis.

10-4.2 **SCUBA Operations.** For SCUBA operations, analyze the nitrox mix in each bottle to be used prior to every dive.

10-4.3 Special Procedures. In the event there is a switch to air during the NITROX dive, using the diver's maximum depth and bottom time follow the U.S. Navy Air Decompression Table for the actual depth of the dive.

10-4.4 Omitted Decompression. In the event that the loss of gas required a direct ascent to the surface, any decompression requirements must be addressed using the standard protocols for "omitted decompression." For omitted decompression dives that exceed the maximum depth listed on Table 10-1, the diving supervisor must rapidly calculate the diver's EAD and follow the omitted decompression procedures based on the diver's EAD, not his or her actual depth. If time will not permit this, the diving supervisor can elect to use the diver's actual depth and follow the omitted decompression procedures.

10-4.5 Dives Exceeding the Normal Working Limit. The EAD Table has been developed to restrict dives with a ppO_2 greater than 1.4 ata and limits dive duration based on CNS oxygen toxicity. Dives exceeding the normal working limits of Table 10-1 require the Commanding Officer's authorization and are restricted to surface-supplied diving equipment only. All Equivalent Air Depths provided below the normal working limit line have the maximum allowable exposure time listed alongside. This is the maximum time a diver can safely spend at that depth and avoid CNS oxygen toxicity. Repetitive dives are not authorized when exceeding the normal working limits of Table 10-1.

10-5 NITROX REPETITIVE DIVING

Repetitive diving is possible when using NITROX or combinations of air and NITROX. Once the EAD is determined for a specific dive, the Standard Navy Air Tables are used throughout the dive using the EAD from Table 10-1.

The Residual Nitrogen Timetable for Repetitive Air Dives will be used when applying the EAD for NITROX dives. Determine the Repetitive Group Designator for the dive just completed using either Table 9-7, Unlimited/No-Decompression Limits and Repetitive Group Designation Table for Unlimited/No-Decompression Air Dives or Table 9-8, U.S. Navy Standard Air Decompression Table.

Enter Table 9-7, Residual Nitrogen Timetable for Repetitive Air Dives, using the repetitive group designator. If the repetitive dive is an air dive, use Table 9-7 as is. If the repetitive dive is a NITROX dive, determine the EAD of the repetitive dive from Table 10-1 and use that depth as the repetitive dive depth.

10-6 NITROX DIVE CHARTING

The NITROX Diving Chart (Figure 10-1) should be used for NITROX diving and filled out as described in Chapter 9. The NITROX chart has additional blocks for the EAD and the percentage of gas in the NITROX mix.

DIVING CHART - NITROX

Date

NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)	PERCENTAGE
NAME OF DIVER 2	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)	PERCENTAGE

TENDERS (DIVER 1) AND	TENDERS (DIVER 2) AND

LEFT SURFACE (LS)	DEPTH (fsw)	EAD	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
					L	
		10			R	
					L	
		20			R	
					L	
		30			R	
					L	
		40			R	
					L	
		50			R	
					L	
		60			R	
					L	
		70			R	
					L	
		80			R	
					L	
		90			R	
					L	
		100			R	
					L	
		110			R	
					L	
		120			R	
					L	
		130			R	

PURPOSE OF DIVE	REMARKS
DIVER'S CONDITION	DIVING SUPERVISOR

Figure 10-1. NITROX Diving Chart.

10-7 FLEET TRAINING FOR NITROX

A Master Diver shall conduct training for NITROX diving prior to conducting NITROX diving operations. Actual NITROX dives are not required for this training. The following are the minimum training topics to be covered:

- Pulmonary and CNS oxygen toxicity associated with NITROX diving.
- EAD tables and their association with the Navy air tables.
- Safe handling of NITROX mixtures.

NITROX Charging and Mixing Technicians must be trained on the following topics:

- Oxygen handling safety.
- Oxygen analysis equipment.
- NITROX mixing techniques.
- NITROX cleaning requirements (MIL-STD-1330 Series).

10-8 NITROX DIVING EQUIPMENT

NITROX diving can be performed using a variety of equipment that can be broken down into two general categories: surface-supplied or closed- and open-circuit SCUBA. Closed-circuit SCUBA apparatus is discussed in Chapter 17.

10-8.1 Open-Circuit SCUBA Systems. Open-circuit SCUBA systems for NITROX diving are identical to air SCUBA systems with one exception: the SCUBA bottles are filled with NITROX (nitrogen-oxygen) rather than air. There are specific regulators authorized for NITROX diving, which are identified on the ANU list. These regulators have been tested to confirm their compatibility with the higher oxygen percentages encountered with NITROX diving.

10-8.1.1 **Regulators.** SCUBA regulators designated for NITROX use should be cleaned to the standards of MIL-STD-1330. Once designated for NITROX use and cleaned, the regulators should be maintained to the level of cleanliness outlined in MIL-STD-1330.

10-8.1.2 **Bottles.** SCUBA bottles designated for use with NITROX should be oxygen cleaned and maintained to that level. The bottles should have a NITROX label in large yellow letters on a green background. Once a bottle is cleaned and designated for NITROX diving, it should not be used for any other type of diving (Figure 10-2).

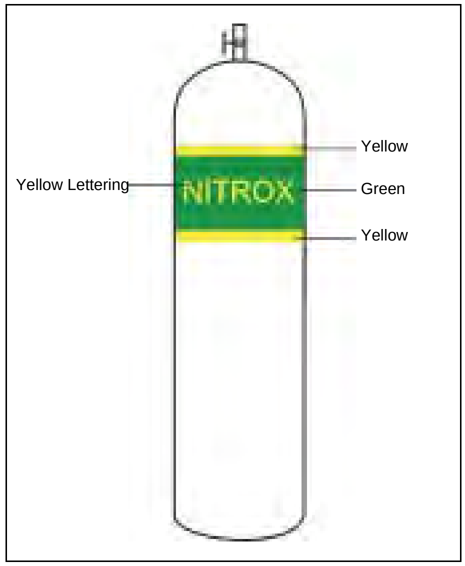

Figure 10-2. NITROX SCUBA Bottle Markings.

10-8.2 **General.** All high-pressure flasks, SCUBA cylinders, and all high-pressure NITROX charging equipment that comes in contact with 100 percent oxygen during NITROX diving, mixing, or charging evolutions must be cleaned and maintained for NITROX service in accordance with the current MIL-STD-1330 series.

10-8.3 **Surface-Supplied NITROX Diving.** Surface-supplied NITROX diving systems must be modified to make them compatible with the higher percentage of oxygen found in NITROX mixtures. A request to convert the system to NITROX must be forwarded to NAVSEA 00C for review and approval. The request must be accompanied by the proposed changes to the Pre-survey Outline Booklet (PSOB) permitting system use with NITROX. Once the system is designated for NITROX, it shall be labeled NITROX with large yellow letters on a green background. MIL-STD-1330D outlines the cleanliness requirements to which a surface-supplied NITROX system must be maintained.

Once a system has been cleaned and designated for NITROX use, only air meeting the requirements of Table 10-2 shall be used to charge the system gas flasks. Air diving, using a NITROX designated system, is authorized if the air meets the purity requirements of Table 10-2.

The EGS used in surface-supplied NITROX diving shall be filled with the same mixture that is being supplied to the diver ± 0.5 percent.

10-9 EQUIPMENT CLEANLINESS

Cleanliness and the procedures used to obtain cleanliness are a concern with NITROX systems. MIL-STD-1330 is applicable to anything with an oxygen level higher than 25 percent by volume. Therefore, MIL-STD-1330 must be followed when dealing with NITROX systems. Personnel involved in the maintenance and repair of NITROX equipment shall complete an oxygen clean worker course, as described in MIL-STD-1330. Even with oxygen levels of 25 to 40 percent, there is still a greater risk of fire than with compressed air. Materials that would not normally burn in air may burn at these higher O_2 levels. Normally combustible materials require less energy to ignite and will burn faster. The energy required for ignition can come from different sources, for example adiabatic compression or particle impact/spark. Another concern is that if improper cleaning agents or processes are used, the agents themselves can become fire or toxic hazards. It is therefore important to adhere to MIL-STD-1330 to reduce the risk of damage or loss of equipment and injury or death of personnel.

10-10 BREATHING GAS PURITY

It is essential that all gases used in producing a NITROX mixture meet the breathing gas purity standards for oxygen (Table 4-3) and nitrogen (Table 4-5). If air is to be used to produce a mixture, it must be compressed using an oil free NITROX approved compressor or meet the purity requirements of oil free air (Table 10-2). Prior to diving, all NITROX gases shall be analyzed using an ANU approved O_2 analyzer accurate to within ± 0.5 percent.

10-11 NITROX MIXING

NITROX mixing can be accomplished by a variety of techniques to produce a final predetermined nitrogen-oxygen mixture. The techniques for mixing NITROX are listed as follows:

1. **Continuous Flow Mixing**. There are two techniques for continuous flow mixing:

   a. **Mix-maker.** A mix-maker uses a precalibrated mixing system that proportions the amount of each gas in the mixture as it is delivered to a common mixing chamber. A mix-maker performs a series of functions that ensures accurate mixtures. The gases are regulated to the same temperature and pressure before they are sent through precision metering valves. The valves are precalibrated to provide the desired mixing pressure. The final mixture can be provided directly to the divers or be compressed using an oil-free compressor into storage banks.

   b. **Oxygen Induction**. Oxygen induction uses a system where low pressure oxygen is delivered to the intake header of an oil-free compressor, where it is mixed with the air being drawn into the compressor. Oxygen flow is adjusted and the compressor output is monitored for oxygen content. When the desired NITROX mixture is attained the gas is diverted to the storage banks for diver use while being continually monitored for oxygen content (Figure 10-3).

2. **Mixing by Partial Pressure**. Partial pressure mixing techniques are similar to those used in helium-oxygen mixed gas diving and are discussed in Chapter 16.

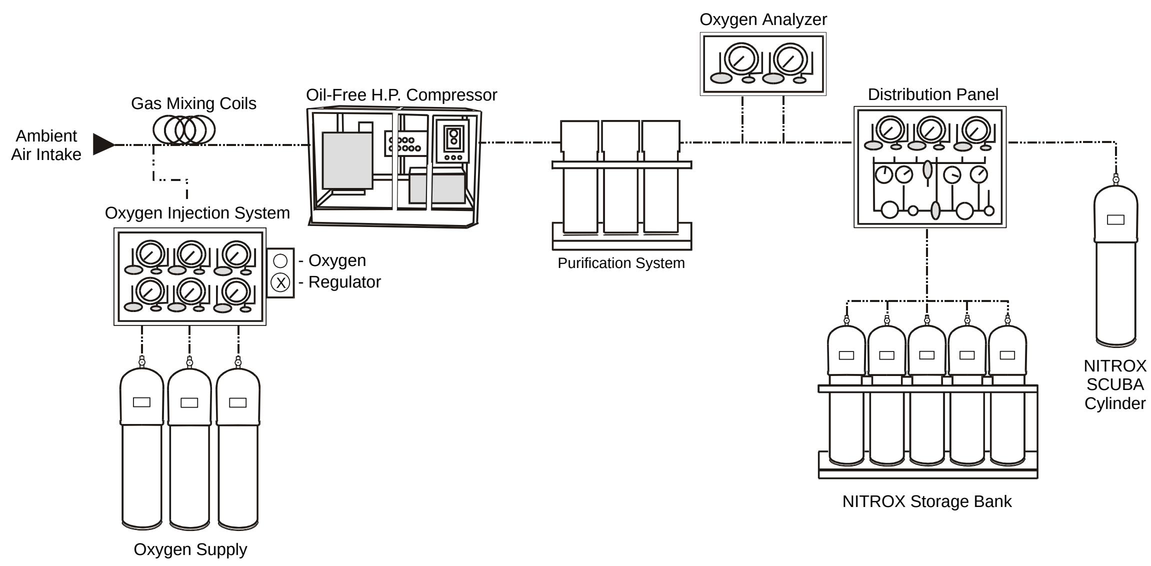

Figure 10-3. NITROX O_2 Injection System.

a. Partial Pressure Mixing with Air. Oil-free air can be used as a Nitrogen source for the partial pressure mixing of NITROX using the following procedures:

- Prior to charging air into a NITROX bottle, the NITROX mixing technician shall smell, taste, and feel the oil-free air coming from the compressor for signs of oil, mist, or particulates, or for any unusual smell. If any signs of compressor malfunction are found, the system must not be used until a satisfactory air sample has been completed.
- Prior to charging with oxygen, to produce a NITROX mix, the NITROX-charging technician shall charge the bottle to at least 100 psi with oil-free air. This will reduce the risk of adiabatic compression temperature increase. Once 100 psi of oil-free air has been added to the charging vessel, the required amount of oxygen should then be added. The remaining necessary amount of oil-free air can then be safely charged into the bottle. The charging rate for NITROX mixing shall not exceed 200 psi per minute.

WARNING **Mixing contaminated or non-oil free air with 100% oxygen can result in a catastrophic fire and explosion.**

- Compressed air for NITROX mixing shall meet the purity standards for “Oil Free Air,” (Table 10-2). All compressors producing air for NITROX mixing shall have a filtration system designed to produce oil-free air that has been approved by NAVSEA 00C3. In addition, all compressors producing oil-free air for NITROX charging shall have an air sample taken within 90 days prior to use.

Table 10-2. *Oil Free Air.*

Constituent	Specification
Oxygen (percent by volume)	20-22%
Carbon dioxide (by volume)	500 ppm (max)
Carbon monoxide (by volume)	2 ppm (max)
Total hydrocarbons [as Methane (CH_4) by volume]	25 ppm (max)
Odor	Not objectionable
Oil, mist, particulates	0.1 mg/m^3 (max)
Separated Water	None
Total Water	0.02 mg/1 (max)
Halogenated Compounds (by volume):	
Solvents	0.2 ppm (max)

3. **Mixing Using a Membrane System**. Membrane systems selectively separate gas molecules of different sizes such as nitrogen or oxygen from the air. By removing the nitrogen from the air in a NITROX membrane system the oxygen percent is increased. The resulting mixture is NITROX. Air is fed into an in-line filter canister system that removes hydrocarbons and other contaminants. It is then passed into the membrane canister containing thousands of hollow membrane fibers. Oxygen permeates across the membrane at a controlled rate. The amount of nitrogen removed is determined by a needle valve. Once the desired nitrogen-oxygen ratio is achieved, the gas is diverted through a NITROX approved compressor and sent to the storage banks (see Figure 10-4 and Figure 10-5). Membrane systems can also concentrate CO_2 and argon.

4. **Mixing Using Molecular Sieves**. Molecular sieves are columns of solid, highly selective chemical absorbent which perform a similar function to membrane systems, and are used in a similar fashion. Molecular sieves have the added advantage of absorbing CO_2 and moisture from the feed gas.

5. **Purchasing Premixed NITROX**. Purchasing premixed NITROX is an acceptable way of obtaining a NITROX mixture. When purchasing premixed NITROX it is requisite that the gases used in the mixture meet the minimum purity standards for oxygen (Table 4-3) and nitrogen (Table 4-5).

10-12 NITROX MIXING, BLENDING, AND STORAGE SYSTEMS

NITROX mixing, blending, and storage systems shall be designed for oxygen service and constructed using oxygen-compatible material following accepted military and commercial practices in accordance with either ASTM G-88, G-63, G-94, or MIL-STD-438 and -777. Commands should contact NAVSEA 00C for specific guidance on developing NITROX mixing, blending, or storage systems. Commands are not authorized to build or use a NITROX system without prior NAVSEA 00C review and approval.

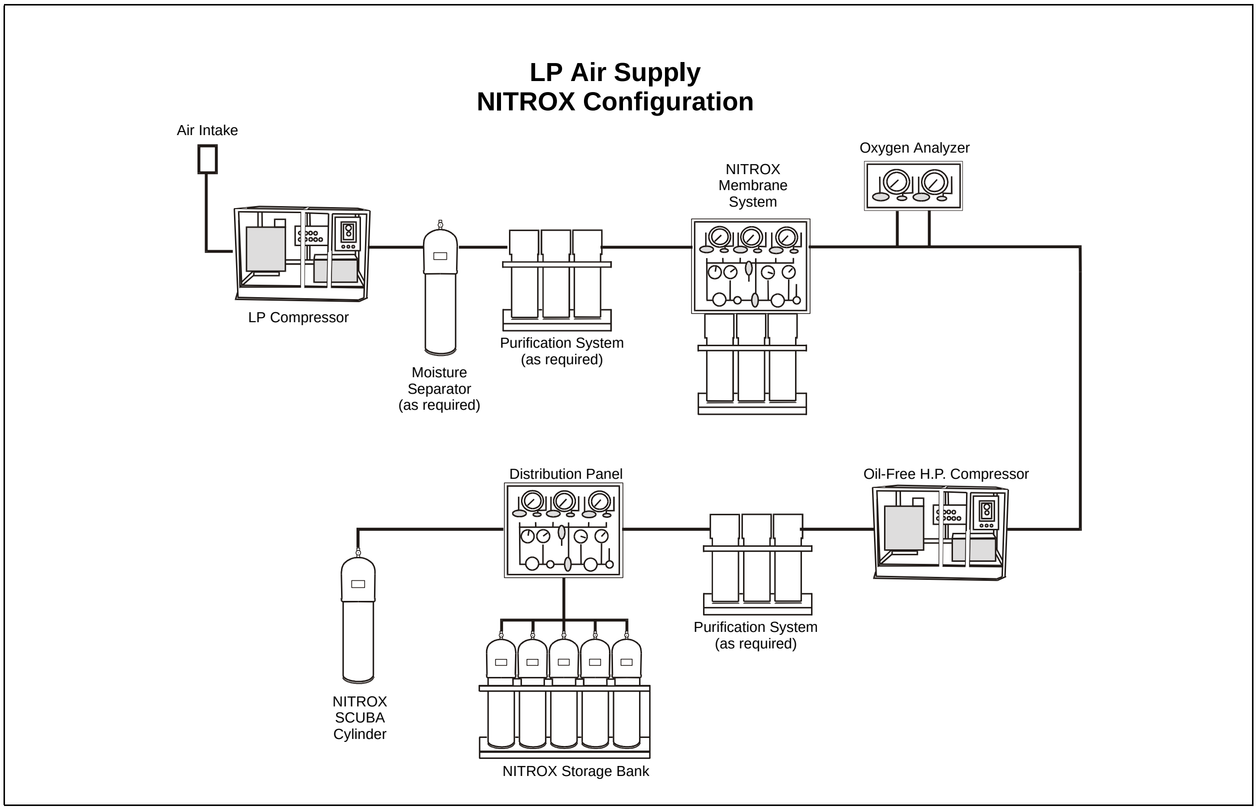

Figure 10-4. LP Air Supply NITROX Membrane Configuration.

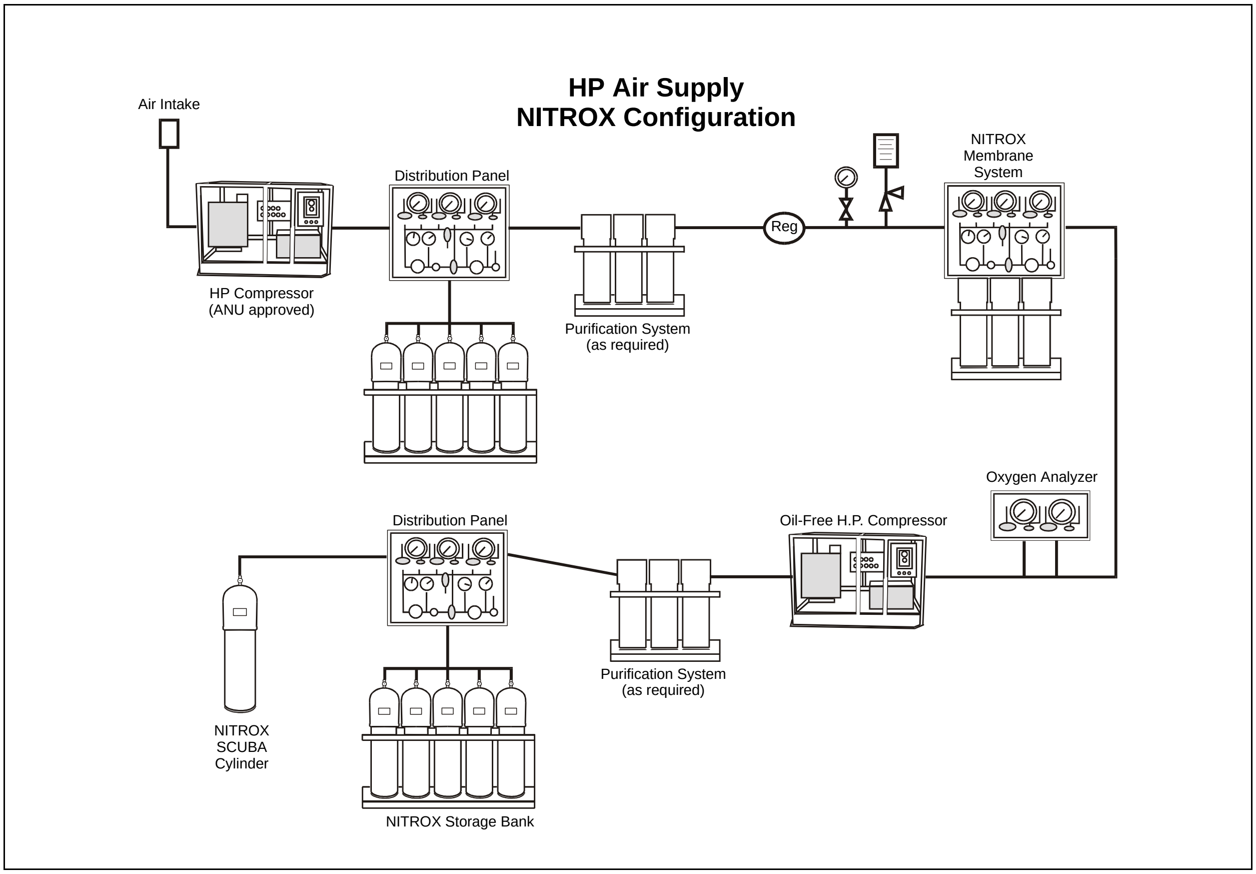

Figure 10-5. HP Air Supply NITROX Membrane Configuration.

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CHAPTER 11

Ice and Cold Water Diving Operations

11-1 INTRODUCTION

11-1.1 Purpose. This chapter explains the special requirements for ice and cold water diving.

11-1.2 Scope. 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.

11-2 OPERATIONS PLANNING

Normal diving procedures generally apply to diving in extremely cold environments. However, there are a number of significant equipment and procedural differences that enhance the diver's safety.

11-2.1 Planning Guidelines. The following special planning considerations relate to diving under/near ice cover or in water at or below a temperature of 37°F:

- The task and requirement for ice diving should be reviewed to ascertain that it is operationally essential.
- Environmental conditions such as 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 or cold water diving experience.
- The type of dive equipment chosen must be suited for the operation.
- Logistical planning must include transportation, ancillary equipment, provisioning, fuel, tools, clothing and bedding, medical evacuation procedures, communications, etc.

NOTE **The water temperature of 37°F was set as a limit as a result of Naval Experimental Diving Unit's regulator freeze-up testing. For planning purposes, the guidance above may also be used for diving where the water temperature is above 37°F.**

11-2.2 Navigational Considerations. Conditions in cold and ice-covered water affect diver underwater navigation in the following ways:

- The proximity of the magnetic pole in polar regions makes the magnetic compass useless.

- The life of batteries in homing beacons, strobes, and communication equipment is shortened when used in cold water.

- 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 and therefore no ripple patterns on the bottom to use for general orientation.

11-2.3 **Scuba Considerations.** Scuba equipment has advantages and disadvantages that should be considered when planning a cold water dive.

The advantages of using scuba are:

- Portability
- Quick deployment
- Minimal surface-support requirements

The disadvantages of using scuba are:

- Susceptibility of regulator to freezing
- Depth limitations
- Limited communications
- Severely limited ability to employ decompression diving techniques
- Duration limitations of CO_2 removal systems in closed-circuit UBA

11-2.4 **Scuba Regulators.** Refer to the ANU for selection of proper regulator. The single-hose regulator is susceptible to freezing. The first and/or second stage of the single-hose regulator may freeze in the free-flow position after a few minutes of exposure in cold water. 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 (Figure 11-1).

Figure 11-1. Ice Diving with Scuba. Divers in Typhoon dry suits and Aga/Divator FFM Scuba with approved cold-water regulators.

11-2.4.1 **Special Precautions.** Single-hose regulators should be equipped with an anti-freeze cap, which is 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 are 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.

11-2.4.2 **Octopus and Redundant Regulators.** 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) shall be used.

11-2.5 **Life Preserver.** The use of life preservers with CO_2 actuation is prohibited only when diving under ice. The accidental inflation of a life preserver 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.

11-2.6 **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 cold water fogging.

11-2.7 **Scuba Equipment.** The minimum equipment required by every Navy scuba diver for under-ice operations consists of:

- Wet suit/variable volume dry suit
- Approved cold water open-circuit scuba or closed-circuit UBA, see ANU
- Face mask or approved Full Faced Mask, see ANU
- Weight belt and weights as required
- Knife and scabbard
- Swim fins
- Wrist watch
- Depth gauge
- Submersible scuba bottle pressure gauge
- Harness such as an Integrated Divers Vest (IDV), MK 12 jocking harness, etc.
- Lifelines
- Stainless Steel Ice Screws

A variety of special equipment, such as underwater cameras and lift bags, is available to divers [see the NAVSEA/00C Authorized for Navy Use (ANU) list for specific identification of authorized equipment]. However, the effect of extreme cold on the operation of special equipment must be ascertained prior to use.

11-2.8 **Surface-Supplied Diving System (SSDS) Considerations.** Using 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.

11-2.8.1 **Advantages and Disadvantages of SSDS.**

The advantages of using SSDS are:

- 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.

The disadvantages of using SSDS are:

- Air console 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 likely when the water is very cold and the air is warm. Banks of high-pressure cylinders may have to be used.
- Buildup 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.
- Umbilicals are rigid and difficult to maneuver.
- Failure of hot water heater during in-water decompression must be considered during operational planning.

11-2.8.2 **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.

11-2.9 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 that 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.

11-2.9.1 **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.

- Wearing 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.**

11-2.9.2 **Variable Volume Dry Suits.** Variable volume dry 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 subsequent 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.**

11-2.9.3 **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 hot water system failure 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.

11-2.10 **Clothing.** Proper planning must include protecting 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. 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.

11-2.11 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, engine protection kits, and stainless steel ice screws.

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 possibility of surface support personnel falling through the ice, floatable work platforms, such as an inflated Zodiac boat, should be used. With such flotation equipment, the operation could be continued or safely concluded if the ice breaks up.

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.

11-2.12 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.

11-3 PREDIVE PROCEDURES

11-3.1 Personnel Considerations. The supervisor of the dive 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).

11-3.2 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.

11-3.3 **Shelter.** When ice diving is conducted, a shelter must be erected as close as possible to the diving site to reduce the probability of frostbite and equipment freeze-up. Normally, tents are not placed over the dive hole because they 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.

11-3.4 **Entry 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 6 feet by 3 feet, or a triangle with six-foot sides as shown in Figure 11-2. 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, wooden pallets, or burlap bags should be placed on the ice around the hole. Upon completing the dive, the hole must be clearly marked to prevent anyone from falling in accidentally. When possible, the pieces cut from the ice should be replaced to speed up the refreezing process.

11-3.5 **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.

11-3.6 **Navigation Lines.** 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 (see Figure 11-2). 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.

11-3.7 **Lifelines.** Diver tending lines are mandatory when diving under ice to help the diver relocate 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. The preferred method to secure the bitter end of the life-line is

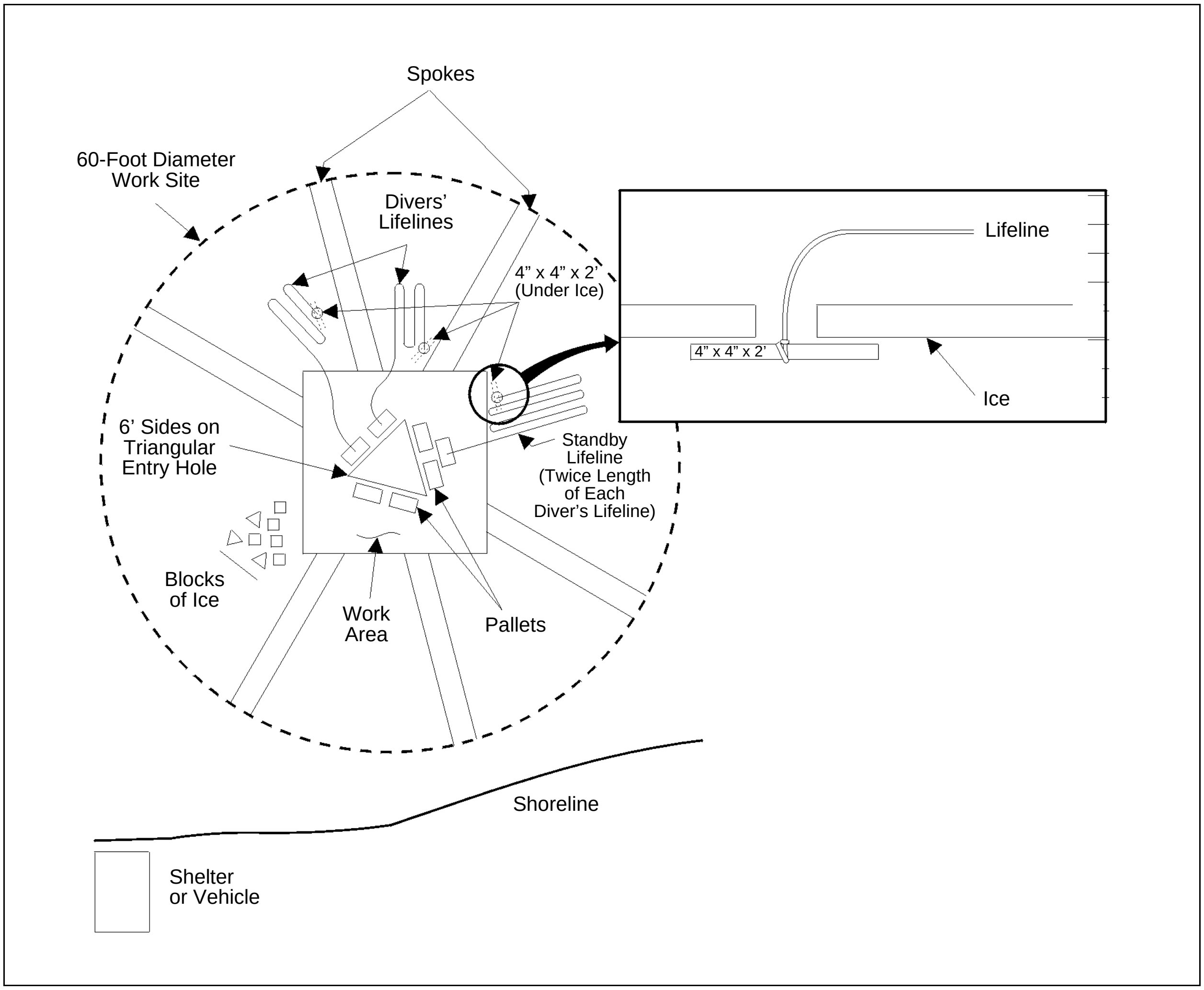

Figure 11-2. Typical Ice Diving Worksite.

with a stainless steel ice screw threaded into the ice. Alternatively, a 4-inch by 4-inch by 2-foot board placed under the ice several yards away from the dive hole can be used to secure the bitter end of the lifeline (see Figure 11-2). 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. The snap hooks should be checked for corrosion at frequent intervals. A wet lifeline must be kept off the bare ice to prevent it from freezing to the surface.

11-3.8 **Equipment Preparation.** The diver must wear a distress light that should be turned on upon entering the water. Divers should not be encumbered with unnecessary equipment during cold water dives. Snorkels 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.

11-4 UNDERWATER PROCEDURES

11-4.1 Buddy Diving. Diving under the ice or in extremely cold waters requires the use of paired dive partners. When diving through the ice, the pair 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 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. Using approved cold water scuba equipment will minimize or eliminate freeze-up problems (see paragraph 11-2.3).

11-4.2 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 11-2). 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 8.

Tending line sensitivity and awareness of the diver's position by tenders may be difficult with the added factors of lifeline drag on subsurface ice formations, line drag over the lip of the under-ice hole, tending through heavy mittens, and the lack of surface bubbles.

11-4.3 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.

11-5 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 7 This section outlines some of the precautions for operating in cold and ice-covered water.

11-5.1 General Precautions. General precautions for ice and cold water diving operations include:

- 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.

- Bathing is 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.

11-5.2 Ice Conditions. 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.

11-5.3 Dressing Precautions. With a properly fitting suit and all seals in place, the diver can usually be kept warm and dry for short periods in even the coldest water. When dressing for an ice or cold water dive:

- 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.

11-5.4 On-Surface Precautions. While on the surface:

- 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. Surface time can also cool metal components of the diving gear, such as suit valves and scuba regulators, below the freezing point and cause the parts to ice up when the diver enters 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 jeopardize the divers' safety.

11-5.5 In-Water Precautions.

- Because severe chilling can result in impaired judgment, 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.

- If the exposure suit tears or floods, 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 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. The progressive hypothermia associated with long, slow cooling of the body appears to cause significant core temperature drop before shivering and heat production begins.

11-5.6 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 to 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-alcoholic beverages available to them.

11-6 EMERGENCY PROCEDURES

11-6.1 Lost Diver.

11-6.1 Lost Diver. A diver who becomes detached from the lifeline and cannot locate the entrance hole should:

1. Ascend to the underside of the ice.
2. Remove weight belt and allow it to drop.
3. Thread an ice screw onto underside of 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.

11-6.2 Searching for a Lost Diver. As soon as the tender fails to get a response from the diver, the tender must notify the Diving Supervisor immediately. These procedures are to be implemented at once:

1. The Diving Supervisor shall 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. The standby diver conducts a circular sweep.
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. If the first sweep fails, it should be repeated only once before moving the search to the most likely emergency hole.

11-6.3 **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; 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.

11-7 ADDITIONAL REFERENCES

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-A5-MAN-010 (Naval Coastal Systems Center) (NCSC)
- *Guide to Polar Diving* (Office of Naval Research, June 1976)
- *UCT Arctic Operation Manual* NAVFAC P-992
  (To obtain a copy of this manual, contact NCSC, Code 5110.)