SATURATION SYSTEMS INC.
SAN DIEGO, CALIFORNIA

VOLUME 1

AIR DIVING

SUPERVISOR OF DIVING
UNITED STATES NAVY

U S NAVY DIVING MANUAL

NAVSHIPS 0994-001-9010

FOREWORD

Navy Department
Naval Ship Systems Command

1 September 1973

The U. S. Navy Diving Manual (NAVSHIPS 0994-001-9010 September 1973) supersedes the U.S. Navy Diving Manual of March 1970.

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

This edition of the U. S. Navy Diving Manual represents one of the most comprehensive revisions of this manual since its inception. The intent is to present to the divers of the U. S. Navy the most current information in the field of diving. The format is so designed that, as advances in diving are made, this manual can be kept current by the addition of new material.

John H. Boyd, Jr.
Captain, U. S. Navy
Supervisor of Diving

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VOLUME 1 AIR DIVING

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SEPTEMBER 1973

Navy Department
Washington, D. C. 20350

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SPECIAL NOTE:

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

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

Department of the Navy
Naval Ships Systems Command
Washington, D. C. 20360
Attn: Supervisor of Diving-OOC

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

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

RECORD OF CHANGES—VOLUME I—AIR DIVING

NAVSHIPS 0994-001-9010
SEPTEMBER 1973

CHANGE NUMBER	DATE OF CHANGE	DATE ENTERED	BY WHOM ENTERED

PREFACE

From its inception in 1916 it has been the tradition of the U. S. Navy Diving Manual to strive to present the most comprehensive information possible concerning diving. Although the art and science of diving have their roots in antiquity, the technical developments of the past decade overshadow any other period in diving history. As a consequence of this growing technology and extensive improvements in established practices and equipment, this edition of the manual reflects one of the most comprehensive revisions ever prepared.

For the first time the manual has been separated into two volumes—Volume No. 1 (Air Diving) and Volume No. 2 (Mixed-Gas Diving). This change, based upon the experience and suggestions of many Navy divers, serves several purposes. The division reflects the qualification and training requirements of Navy divers and other users, improves clarity and simplifies referencing. Future revisions of the manual are also facilitated by the separation of fundamental air diving technology from the rapidly changing field of mixed-gas diving.

The manual has been completely rewritten, and the format has been changed. The volumes are tab-indexed for quick reference and incorporate more illustrations, photographs and charts than previous editions. The loose-leaf style of the manual has been retained to simplify the addition of new data as it becomes available.

This edition of the U. S. Navy Diving Manual incorporates several major new areas of diving technology. Included are the application of deep diving systems and associated diver breathing apparatus, saturation diving and lightweight equipment for mixed-gas operations. Many new types of equipment are also discussed for the first time. Noteworthy additions are single-hose SCUBA regulators, improved voice communications equipment, hot water suits, helium-voice unscramblers, deep diving systems, the MK 1 lightweight mask, and mixed-gas underwater breathing apparatus.

Many established procedures and techniques of diving have been revised, expanded or clarified. The topic of diving operations planning, a key element of safe and efficient diving, has been expanded. The characteristics and selection of air supply systems are discussed in greater detail. Several new aspects of underwater physiology of particular importance in deep diving, such as pulmonary oxygen toxicity, minimum inspired gas temperatures and the high pressure nervous syndrome, are introduced. Simplified instructions have been prepared for the administration of oxygen recompression treatment and recognition of the signs and symptoms of decompression sickness.

Decompression tables and their format have been extensively revised. Mixed-gas tables have been separated into three indexed categories—SCUBA, surface-supplied (partial pressure) and saturation—for easier referencing. Table numbers have been eliminated to minimize the confusion which has resulted from designation changes associated with frequent revision. Exceptional exposure schedules (printed in red) and normal schedules have been combined.

New data is interwoven throughout the manual. Information is presented on hyperbaric flammability, equipment gas and absorbent usage, gas mixing and analysis, OPNAV 9940/1 record keeping, new depth limits, U.S.N.-approved equipment and useful NAVSHIPS publications.

The field of diving is dynamic, and it has been the intent of this edition of the manual to include the most timely, authoritative and safest information possible. The contents of this manual represent the distillation of countless years of experience and experimentation by Navy divers. From the lessons to be learned from the history of diving to the understanding to be gained of saturation diving procedures, this manual offers all divers hard-won knowledge which can improve the efficiency and safety of all diving operations. It is to this group, the past, present and future divers of the U. S. Naval Forces, that this edition of the U. S. Navy Diving Manual is dedicated.

J H Boyd Jr

John H. Boyd, Jr.
Captain, U. S. Navy
Supervisor of Diving

CHAPTER ONE

HISTORY OF DIVING

Figure 1-1 This sixth-century B.C. vase shows a Greek diver about to descend, probably in search for sponges.

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

No one knows when man first discovered that he could hold his breath and go under water, but the beginnings of diving as a profession can be traced back more than 5000 years. These early diving efforts were confined to relatively shallow waters (less than 100 feet), with the divers harvesting a variety of materials of commercial value including food, sponges, coral and mother-of-pearl.

One of the first records of such diving is found in the writings of the Greek historian Herodotus. He tells the story of a diver named Scyllis, who was employed by the Persian King Xerxes to recover sunken treasure in the 5th century B.C.

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

Other early divers developed an active salvage industry centered around the major shipping ports of the eastern Mediterranean. By the first century B.C., operations in one area had become so well organized that a scale of payment for salvage work was established by law acknowledging the fact that effort and risk increased with depth. In 24 feet of water, the divers could claim a one-half share of all goods recovered. In 12 feet of water they were allowed a one-third share; and, in 3 feet, only a one-tenth share.

The techniques of these primitive divers are still used today in a few areas of the world. The breath-holding skin diver trains from childhood, developing exceptional lung capacity, stamina and confidence. He fills his lungs with air and grasps a stone or other weight to accelerate his descent to the bottom. By using a flat stone, he can steer a course toward a target area; and often, the divers work with a rope tied to their waists so that a co-worker can assist in bringing the diver, the stone, and the payload back to the surface.

These dives usually have a duration of one to two minutes, which is roughly the length of time that an average man can hold his breath on dry land. The average depth ranges from 80 to 100 feet. The trained skin diver has no difficulty in achieving this standard even with the extra exertion of working underwater, and many dives have been recorded of greater duration and to greater depths. However, repeated breathhold diving of this type can have a cumulative debilitating effect on the human system.

EARLY DEVELOPMENTS 1.1

The most obvious and necessary step in broadening the capabilities of a diver was to provide an air supply that would permit him to stay underwater. The first such efforts used hollow reeds or tubes extending to the surface. The user could remain submerged for an extended period of time, but could accomplish little in

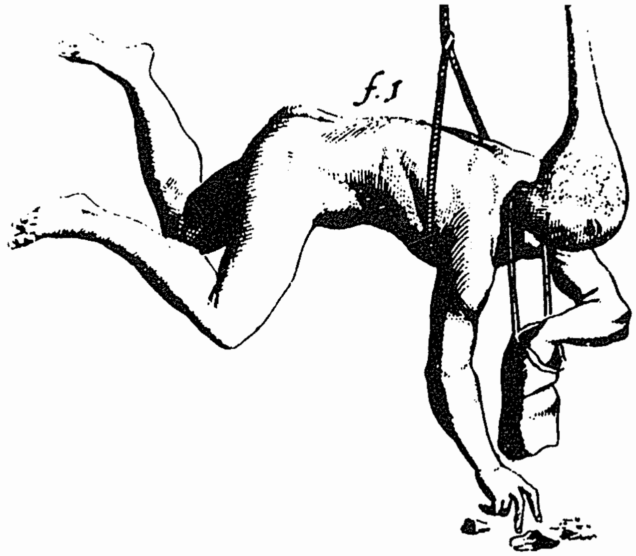


Figure 1-2 This 1511 design shows the diver's head encased in a leather bag with a breathing tube to the surface.

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

the way of useful work. Breathing tubes were employed mainly as a tactic in military operations where they permitted an undetected approach to an enemy stronghold. Men using these tubes were not so much divers as they were soldiers using the water as a cover for their mission.

At first glance, it would seem logical that the only thing needed to further extend the range of the diver would be a longer tube. In fact, a number of early designs were created following that concept—leather hoods with long flexible tubes supported at the surface by floats. There is no record that any of these devices were actually constructed; and, if any were tested under actual conditions, the result may well have been the drowning of the user. Even at a shallow depth of 12 inches, it is essentially impossible to breathe through a tube using only the body's natural respiratory ability since the weight of the water exerts a total force of almost 200 pounds on the diver's chest. This force increases steadily with depth and is one of the most important factors in diving. Any succesful diving operation requires that the pressure be overcome or eliminated. Throughout history, imaginative devices were designed to accomplish this, many by some of the greatest minds of the time; but, because the problem of pressure underwater was not fully understood, the designs were impractical.

An entire series of designs were based on the idea of a breathing bag carried by the diver. This concept may be quite old since an Assyrian frieze of the 9th century B.C. shows what appear to be divers using inflated animal skins as air tanks. However, these men were more probably swimmers using the skins for flotation. It would be virtually impossible to submerge while holding such an accessory.

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

Other writers, in the 16th and 17th centuries, described and published drawings of equipment which foreshadowed later successful developments. However, it is doubtful that these designs had any substantial influence, and to give undue credit to the inventors of that period would be similar to giving Jules Verne credit for inventing the nuclear submarine. Verne had the imagination and foresight, but lacked the necessary supporting technology.

Early Successes 1.1.1 During the general period 1500-1800, a device was developed and placed in use which enabled divers to remain underwater for lengths of time measured in hours rather than minutes. This was the diving bell.

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

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

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

In 1690 the English astronomer Edmund Halley (who predicted the periodic return of the comet which bears his name) developed a diving bell in which the atmosphere was replenished by sending weighted barrels of air down from the surface. In an early demonstration of his system, he and four other people remained at 60 feet under the Thames River for almost 1.5 hours. Nearly 26 years later, using an improved version of his bell, Halley, then 65 years old, spent more than four hours at a depth of 66 feet.

In 1715, another Englishman—John Lethbridge—developed a one-man completely enclosed diving dress. The Lethbridge equipment was essentially a reinforced, leather-covered barrel of air, equipped with a glass porthole for viewing, and having two arm holes with water-tight sleeves, thereby permitting the occupant to accomplish useful work. This apparatus was slung from a ship and maneuvered in the same manner as a diving bell.

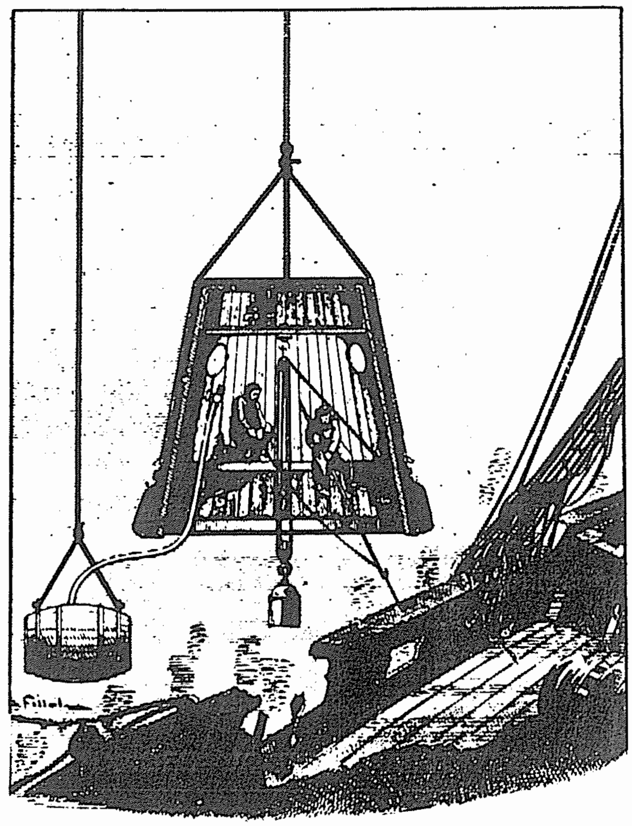


Figure 1-4 More advanced diving bells, such as these designed by Halley, included weighted barrels of air to replenish their atmosphere.

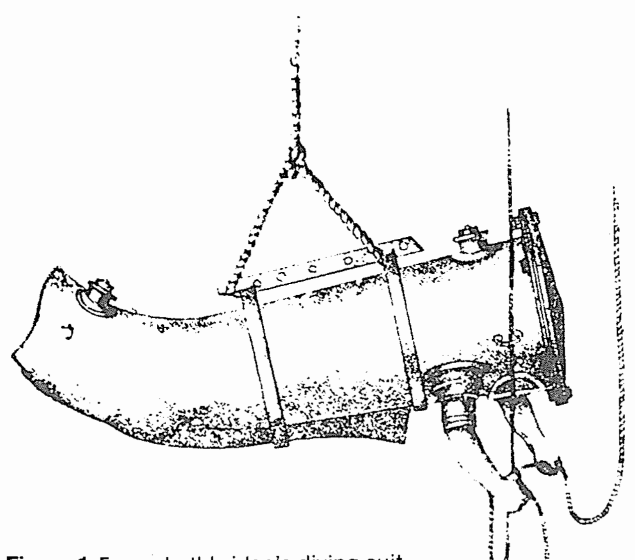


Figure 1-5 Lethbridge's diving suit.

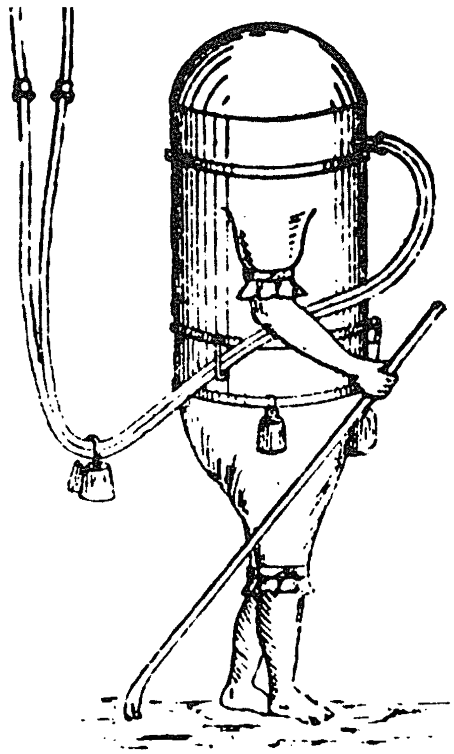


Figure 1-6 Successful enclosed diving dress.

Lethbridge was apparently quite successful with his invention and participated in the salvage of a number of wrecks in various waters of Europe. 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) with about 12 fathoms the maximum, and that he could remain underwater for 34 minutes.

Several other designs similar to Lethbridge's appeared and were used in succeeding years. However, they all suffered from the same basic limitation as the diving bell: the diver had little freedom because there was no practical way to continually supply him with air. A true technological breakthrough occurred at the turn of the 19th century with the development of a pump capable of delivering air under pressure.

The Deep-Sea Diver 1.1.2 The art and practice of salvage diving was well developed as England entered the industrial revolution in the middle of the 18th century. Using diving bells, devices similar to that of Lethbridge, or simple skin diving in shallow waters,

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

salvage operators were very active recovering everything from lost anchors to gold coins and silver ingots. While the common man was always fascinated by the search for "sunken treasure," such finds were rare and the day-to-day financial rewards came from more mundane but surprisingly valuable scrap. The brass to be recovered just from the ordnance of a 100-gun ship of the line was worth more than $50,000 in the money of the day. And, with perhaps 1000 new military and civilian wrecks littering the shores of Great Britain each year, there was a strong incentive for the development of a diving dress which would increase the efficiency of salvage operations.

Traditional credit for the development of the first practical diving dress has been given to Augustus Siebe. Actually he was only one of several men who produced a successful apparatus at the same time.

John and Charles Deane, two brothers who became active in the salvage business, obtained patents in 1823 on the basic design for a "smoke apparatus" to permit firemen to move about in burning buildings. By 1828 this had 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 bringing in surface-supplied air. The helmet was not fastened to the suit, but simply rested on the driver's shoulders, held in place by its own weight and by straps to a waist belt. The exhausted or surplus air passed out from under the edge of the helmet, and posed no problem as long as the diver was standing upright. However, should he trip and fall the helmet could quickly fill with water.

The Deanes were well enough organized as salvage operators that in 1836 they even issued a diver's manual—perhaps the first ever produced.

Augustus Siebe's initial contribution to diving was essentially a modification of the Deane outfit. Siebe "sealed" the helmet to the dress at the collar by using a short, waist-length suit which permitted the exhaust air to escape under the hem. By 1840, Siebe had adopted a full-length waterproof suit and added an exhaust valve to the system. Known as "Siebe's Improved Diving Dress," this apparatus is the direct ancestor of the standard deep-sea diving dress in widespread use today.

By 1840, several other types of diving dress had appeared on the scene and were being used in actual diving operations. At that time, a unit of the British Royal Engineers was engaged in the sizable project of removing the remains of a sunken warship (HMS ROYAL GEORGE), which was fouling a major fleet anchorage just outside of 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. His testing eliminated one outfit (Bethell's apparatus) from further consideration because the method of fastening the helmet to the suit was too cumbersome and time-consuming. He was wary of the Deane apparatus because of the safety factor; and therefore, formally recommended that the Siebe dress be adopted for any future operations.

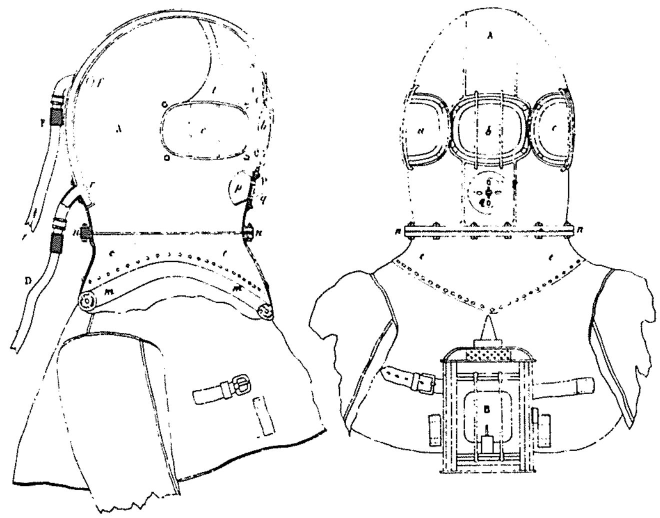


Figure 1-8 Deanes' "smoke apparatus."

Figure 1-9 Siebe's first "closed" diving dress and helmet.

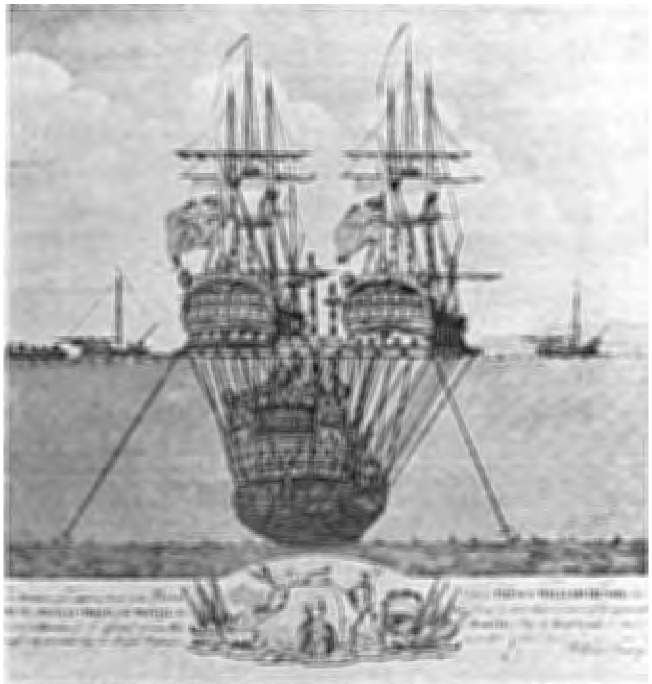


Figure 1-10 The salvage of the ROYAL GEORGE.

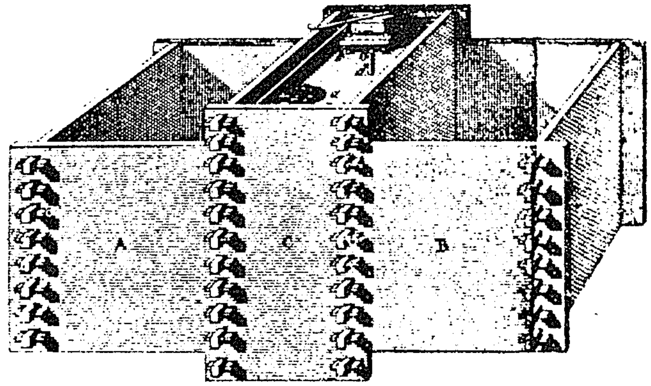


Figure 1-11 This French caisson could be floated over the worksite and lowered to the bottom by flooding the tanks on either side.

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

The Mysterious Malady 1.1.3 At the same time that a practical diving dress was being perfected, other inventors were working to improve the diving bell by increasing its size and adding high-capacity air pumps capable of delivering sufficient pressure to keep water entirely out of the interior of the bell. This improved pump capability soon led to the construction of chambers large enough to permit several men to engage in dry work on the bottom. This was particularly advantageous in such projects as excavation of bridge footings or the construction of tunnel sections where long periods of work were required. These dry chambers came to be known by the French word caisson which literally means "big box."

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

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

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

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

Today, the bends is the best-known danger of diving, popularized by generations of adventure fiction in books, magazines and television. However, it is not really surprising that it was unknown 150 years ago, even though men had been diving for thousands of years. Until the time of the caisson, few men had spent much time working under any great pressure. Those few individuals such as Pasley, who had experienced some aspect of the disease, were simply not prepared to look for anything more involved than indigestion, rheumatism or arthritis.

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

Bert recommended that caisson workers gradually decompress and that divers return to the surface slowly. His studies led to an immediate improvement for the caisson workers as they also discovered that their pain could be relieved merely by returning to the pressure of the caisson as soon as the symptom appeared. Within a few years, specifically-designed "re-compression" 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 necessary for the particular worker. One of the first successful uses of a recompression chamber was in connection with the construction of a tunnel under the Hudson River, between New York and New Jersey, in 1893. Use of the chamber markedly reduced the number of serious cases and, most importantly, reduced the number of fatalities caused by the bends.

Figure 1-12 Early twin-lock recompression chamber.

Other Physiological Discoveries 1.1.4 Bert's recommendation that divers use a gradual but steady ascent was not a complete success, and some divers continued to suffer from the bends. There was a general feeling at that time that divers had reached the practical limits of the art and that 120 feet was about as deep as anyone could ever really work. This was partly because of the repeated incidence of the bends from deeper dives, and also because of a noted inefficiency on the part of the diver beyond that depth. Occasionally, divers would even lose consciousness working at 120 feet.

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

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

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

It was not long before divers were moving into deeper water, and another unexplained malady began to appear. The diver would seemingly become intoxicated, sometimes feeling euphoric, and frequently losing his sense of judgment to the point where he would forget the purpose of his dive. In the 1920's this "rapture of the deep" was linked to the nitrogen in the air when breathed under higher pressures. Technically known as nitrogen narcosis, it was shown that nitrogen has anaesthetic properties which become progressively more severe with increasing air pressure. To avoid the problem today, special breathing mixtures such as helium/oxygen are used instead of air for deep diving.

Armored Diving Suits 1.1.5 Numerous inventors, many having little or no experience underwater, worked to create an armored diving suit which would free the diver from any and all problems of pressure. In such a suit, he could breathe air at normal atmospheric pressure and, hopefully, could descend to great depths without any ill effects. The barrel diving suit of John Lethbridge was essentially an armored suit, but 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 the protection for extreme pressure that was the goal of the inventors. The maximum design-depth of the various suits developed in the 1930's was 700 feet, and was never reached in actual diving.

Development of the "Free" Diver 1.1.6 Deane, Siebe and the others had given man the ability to remain underwater for extended periods with enough flexibility of movement to accomplish a significant amount of work during his stay. However, the diver was still unalterably tied to the surface. Without the vital umbilical of his air hose, he could not survive, let alone function. While the hose gave him life, it also severely limited his range of operation.

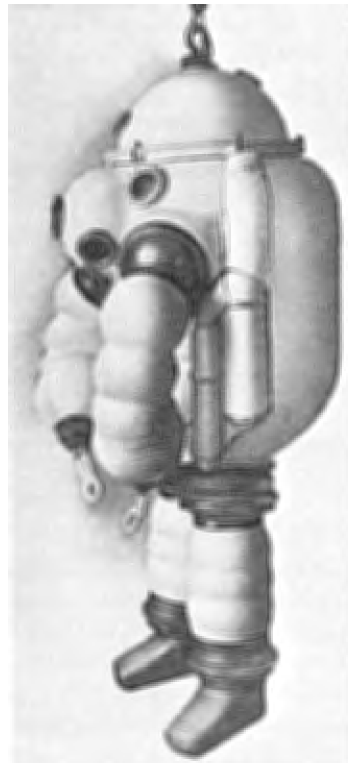


Figure 1-13 Variety of armored diving suit.

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

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

With the **open-circuit apparatus** air is taken from a supply tank, used by the diver, and the exhaust is vented directly to the surrounding water. The basic **closed system** uses a tank of 100% oxygen for breathing, and the gas being used by the diver is recirculated in the apparatus. It passes through a chemical filter which removes carbon dioxide waste, and additional oxygen is added from the tank to replace that which is consumed in breathing. For clandestine military operations the closed-circuit system (oxygen rebreather) has a major advantage over the open-circuit type insofar as it does not produce a telltale trail of bubbles on the surface.

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

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

Historically, the development of self-contained breathing apparatus has involved many significant inventions which, for the lack of supporting components of equivalent capability, could not be fully exploited. Two main paths of development were followed —one pursued open-circuit SCUBA, and the other emphasized its closed-circuit counterpart.

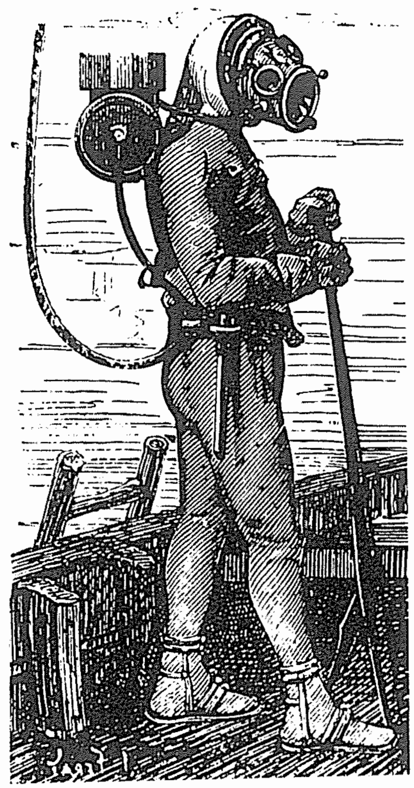


Figure 1-14 Rouquayrol's 1866 demand regulator

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

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

Figure 1-15 Midget submarine used during WWII.

Unfortunately, at the time of his invention, Fleuss was not aware of the serious problem of oxygen poisoning caused by breathing 100% oxygen under pressure. It was not until many years later that researchers determined that the maximum safe depth for use of 100% oxygen was about 25 feet.

Two years after its invention, the Fleuss SCUBA figured prominently in a highly publicized achievement by an English diver, Alexander Lambert. A tunnel under the Severn River had flooded in 1880, and Lambert, wearing a Fleuss apparatus, walked 1000 feet along the tunnel, in complete darkness, to reach and close several crucial valves.

As development of the closed-circuit design continued, the Fleuss equipment was improved by the addition of a demand-regulator and tanks capable of holding oxygen at more than 2000 psi; and, by World War I, the Fleuss SCUBA (with modifications) was the basis for submarine escape equipment used in the Royal Navy.

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

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

At the same time that actual combat operations were being carried out with closed-circuit apparatus, two Frenchmen—one a naval officer, the other an engineer—achieved a significant breakthrough in open-circuit SCUBA design.

Working in a small Mediterranean village under the difficult and restrictive conditions of German-occupied France, Captain Jacques-Yves Cousteau and Emile Gagnan combined an improved demand-regulator and high-pressure air tanks to create the first truly efficient and safe open-circuit SCUBA. Cousteau and his companions brought the "Aqua-Lung" to a high state of development as they explored and photographed wrecks, developing new diving techniques and testing their equipment. Their work was the culmination of literally hundreds of years of progress, and blended the work of Rouquayrol, Fleuss, and LePrieur. Cousteau used his gear successfully to a depth of 180 feet without significant difficulty; and, with the end of the war, the Aqua-Lung quickly became a commercial success. Today, this apparatus represents the most widely used and familiar of diving equipments, opening the underwater world to anyone with suitable training and the necessary physical abilities.

RECENT DEVELOPMENTS 1.2

The underwater freedom brought about by the development of SCUBA has led to a rapid growth of interest in diving. Sport diving is the popular aspect of this interest, but the worlds of science and commerce have also greatly benefited. Biologists, geologists, zoologists and archeologists have all gone underwater, seeking new clues to the origins and behavior of the earth, of man, and of civilization as a whole. An entire industry centered on commercial diving has flourished, with the major portion of activity centered in the area of offshore petroleum production which today yields 14% of the world's oil requirements.

During the post-war era, the art and science of diving progressed rapidly, with an emphasis placed on improving existing diving techniques, creating new methods, and developing the necessary equipment systems 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 the saturation diving technique and the deep diving system.

Saturation Diving 1.2.1 As men dived deeper and attempted more ambitious underwater tasks, the need for a safe method of extending actual working time at depth became evident.

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

However, there is a point beyond which the diver does not need additional decompression—the point at which he becomes "saturated" with the gases which make decompression necessary. Once his blood and tissues have absorbed all of 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.

Figure 1-16 SEALAB II Habitat.

If a diver, or team of divers, had the means to remain under pressure for the entire period of his required task, whether it be days or weeks, he would only have to face a lengthy decompression once—at the very end. For a 40-hour task at 200 feet, a diver, if saturated, would spend 5 days at bottom pressure and two days in decompression, as opposed to a total of 40 working days of single dives and lengthy decompression periods using conventional methods.

The theory of saturation diving was proved through the efforts of three men: Jacques-Yves Cousteau, Edwin A. Link, an American inventor known for his "Link Trainer" which simulates cockpit experience in the training of aviators, and Captain George F. Bond of the U. S. Navy. Each of these men conducted experiments in saturation diving.

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

In 1964, Link expanded his work by putting two men at 432 feet in a habitat for two days and nights. Almost simultaneously, Captain Bond headed the U. S. Navy's first experiment in the SEALAB series. Working off Bermuda, Bond placed four divers at 192 feet for 9 days, eventually raising their habitat to 81 feet where they transferred to a decompression chamber which was then, in turn, hoisted aboard the support vessel.

SEALAB II, which took place a year later, put three teams of 10 men each in a habitat at 205 feet, with each team spending 15 days at depth and one man remaining for 30 days.

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

Deep Diving Systems 1.2.2 Developed almost wholly within the last ten years, Deep Diving Systems (DDS) represent a substantial improvement over any previous methods of accomplishing deep undersea work. The DDS is readily adaptable to saturation techniques, and provides a safe mechanism for maintaining the saturated diver under pressure in a dry environment. Whether employed for saturation or nonsaturation diving, the Deep Diving System totally eliminates the need for long periods of decompression in the water where the diver is subjected to the dangers of extended environmental stresses. Additional benefits derived from use of the DDS include the elimination of the need for underwater habitats and an increase in operational flexibility for the surface support ship.

The system consists basically of a deck decompression chamber (DDC) mounted on a surface support ship, and a personnel transfer capsule (PTC). In an actual operation, two or more divers enter the tethered capsule and descend to the required depth. The interior of the capsule is pressurized to equal the pressure at depth, a hatch is opened, and one or more men swim out to accomplish their work. With a safety tether to the capsule the diver can use self-contained breathing apparatus or employ a mask and an umbilical line which provides breathing gas and communications. Once his task is finished, the diver returns to the capsule, closes the hatch and returns to the support ship with the interior of the capsule still at the bottom pressure. The capsule is hoisted aboard, mated to the pressurized deck decompression chamber, and the divers enter the larger, more comfortable DDC via an entry lock. There, the men remain at pressure until they must return to the undersea job site or they can begin decompression comfortably and safely on the support ship.

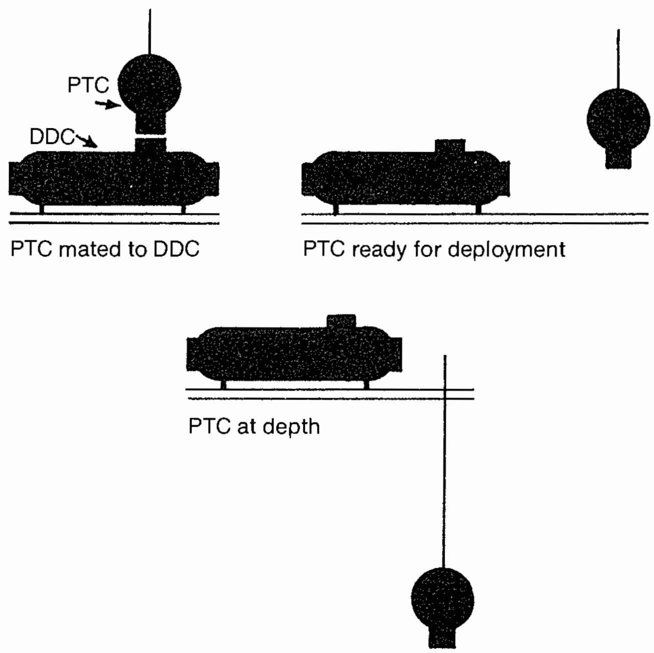


Figure 1-17 Operating sequence of a deep diving system.

DIVING IN THE U. S. NAVY 1.3

The U. S. Navy has been at the forefront of developments in modern diving and underwater operations. The general requirements of national defense and the specific requirements of underwater reconnaissance, demolition, ordnance disposal, underwater construction, ship maintenance, search, rescue, and salvage operations have repeatedly given impetus to training and development. Navy divers are at work every day around the world, covering the spectrum of diving activity: from repairing ships to placing the footings for bridges, from preparing the way for invasion fleets in time of war to clearing harbors in time of peace.

Early History of Navy Diving 1.3.1 The early history of diving in the U. S. Navy parallels that of the other navies of the world. Since the middle of the 19th century, the Navy has employed divers in salvage and repair of ships, in construction work, and in offensive military operations.

For the most part, they were swimmers and skin divers, with techniques and missions unchanged since the days of Alexander the Great. At the Battle of Mobile Bay, for instance, swimmers were sent in ahead of Admiral Farragut's ships, to locate and disarm Confederate "torpedos" (mines) that had been planted to block the entrance to the Bay.

In 1898, Navy divers were briefly involved in an international crisis when the USS MAINE was sunk by a mysterious explosion while anchored in the harbor at Havana, Cuba. Navy divers were sent from Key West to study the wreck and make a report. A Court of Inquiry was convened to investigate the cause of the explosion, but the divers, who were not trained in naval architecture and did not understand ship construction, were unable to say whether the MAINE had been sunk by a Spanish mine or by an internal, accidental, explosion.

The beginning of the 20th Century saw the attention of all major navies turning towards the development of a weapon of immense potential—the military submarine. The highly effective use of the new weapon by the German Navy in World War I heightened this interest, and an emphasis was placed on the submarine that has never slackened.

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

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

The experience gained in Stillson's program was put to dramatic use six months later when the submarine USS F-4 sank near Honolulu, Hawaii. Twenty-one men lost their lives in the accident and the Navy lost its first boat in 15 years of submarine operations. Navy divers salvaged the F-4, and recovered the bodies of the crew. The salvage effort incorporated many new techniques, such as the use of lifting pontoons, but what was most remarkable was that the divers completed a major salvage effort working at the extreme depth of 304 feet using air as a breathing mixture. To this day, these dives remain the record for the use of standard deep-sea diving dress. Because of the depth, and the necessary decompression, each diver could remain on the bottom for only 10 minutes. Even for such a limited time, the men found it hard to concentrate on the job at hand. Unknowingly they were severely affected by nitrogen narcosis.

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

The physiological problems encountered in the salvage of the F-4 clearly demonstrated the limitations of breathing air during deep dives. Continued concern that submarine rescue and salvage would be required at great depth focused Navy attention on the need for a new diver breathing medium. In 1924 the Navy joined with the Bureau of Mines in the experimental use of helium-oxygen mixtures. The preliminary work was conducted at the Bureau of Mines Experimental Station in Pittsburgh, Pennsylvania. Experiments on animals, later verified by studies with human subjects, clearly showed that helium-oxygen mixtures offered great advantages over air for deep dives. There were no undesirable mental effects, and decompression time was improved. This early work

Figure 1-18 The hyperbaric facility at the Experimental Diving Unit has recently been modernized to include some of the most recent developments in chamber control and computerized diver monitoring systems.

laid the foundation for development of reliable decompression tables and specialized apparatus which are the cornerstones of modern deep diving technology.

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

Salvage of the 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.

With interest in diving once again high, the Naval School, Diving and Salvage was re-established at the Washington Navy Yard in 1927. And, 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 following years, EDU developed the U. S. Navy Air Decompression Tables which have become the accepted world standard, as well as continuing developmental work in helium-oxygen breathing mixtures for deeper diving.

The loss of the F-4 and 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.

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

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

The Navy pushed for development of a rescue chamber which, when completed, was essentially a diving bell with special fittings for connection to a submarine deck hatch. The apparatus—the McCann-Erickson rescue chamber—was proven in 1939 when a submarine sank in 243 feet of water. The SQUALUS carried a crew of 50. The rescue chamber made four trips and safely brought 33 men to the surface. The rest of the crew, trapped in the flooded after-section of the submarine, had been killed in the sinking. Salvage divers, using helium-oxygen mixtures raised the boat and,

Figure 1-19 Salvage of the SQUALUS.

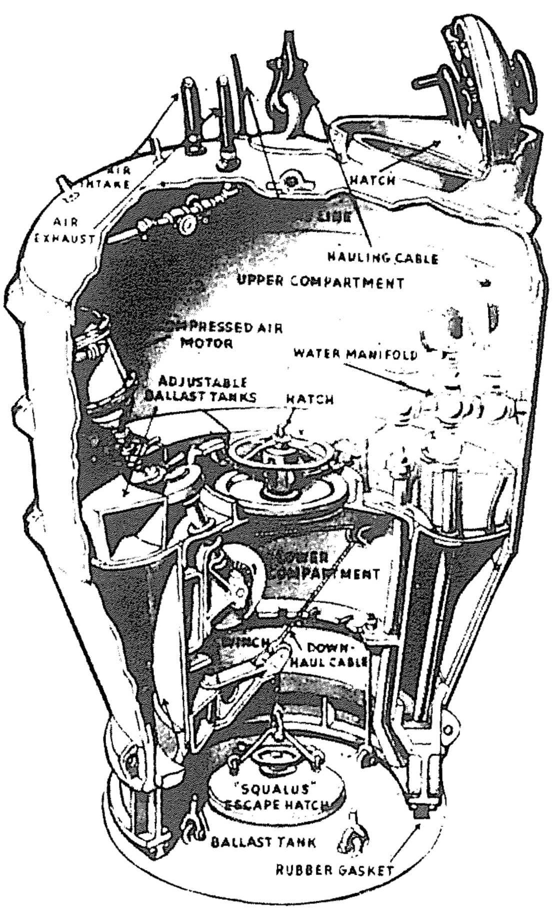


Figure 1-20 Vertical section of the McCann-Erickson rescue chamber.

following renovation and re-named SAILFISH, the submarine compiled a proud record in World War II.

World War II 1.3.2 Navy divers were plunged into the war as dramatically as the rest of the Fleet, with the Japanese raid on Pearl Harbor. The raid began at 0755, 7 December 1941; and, by 0915 that same morning, the first salvage teams were cutting through the hull of the overturned battleship OKLAHOMA to rescue trapped sailors. Teams of divers were put to work recovering ammunition from the magazines of sunken ships, to be ready in the event of a second attack.

The salvage effort that followed at Pearl Harbor was immense—and highly successful. There were 101 ships in the harbor at the time of the attack, and most of them sustained damage. The hardest hit were the battleships, being one of the primary targets of the raid. Six battleships were sunk, and one was heavily damaged. Four of these were salvaged and returned to the fleet for combat duty; one, the OKLAHOMA, was righted and re-floated but sank en route to a shipyard in the United States. Only the ARIZONA and the former battleship UTAH could not be salvaged.

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

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

To clear the vitally needed pier, the ship had to be salvaged—and the Navy took advantage of another unique opportunity for training by establishing a diving and salvage school on the site.

Salvage operations were not, of course, the only missions assigned to Navy divers during the war. Many

Figure 1-21 U. S. Navy salvage operation at Pearl Harbor.

Figure 1-22 Recovery and deployment of Navy UDT "frogmen."

dives were made, for example, to inspect sunken enemy ships and especially to recover materials such as code books, or other intelligence items. One Japanese cruiser yielded not only $500,000 worth of yen, but also provided valuable information concerning plans for the defense of Japan against the anticipated Allied invasion.

Combat Swimmers 1.3.3 The combat diving mission was the same in World War II as it had been in previous wars—to remove obstacles from enemy waters and gather intelligence. The Navy's underwater demolition teams (UDT) were created when bomb disposal experts and SeaBees teamed together in 1943 to devise methods for removing obstacles that the Germans were known to be placing off the beaches of France.

The first UDT combat mission, however, was in the Pacific—a daylight reconnaissance and demolition project off the beaches of Saipan in June, 1944. In March of the next year, in preparation for the invasion of Okinawa, one underwater demolition team achieved the exceptional record of removing 1200 underwater obstacles (mostly foot-thick pilings driven into the bottom) in two days, under heavy fire, without a single casualty.

Diving apparatus was not extensively used by the UDT during the war. No suitable equipment was readily available. UDT experimented with a modified Momsen lung, and with other types of breathing apparatus; but it wasn't until 1947 that the Navy's acquisition of Aqua Lung equipment gave 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 War, during the period of strategic withdrawal, the UDT destroyed an entire port complex to keep it from being used by the enemy.

Today, Navy combat swimmers are organized into three separate groups, each with specialized training and missions. The Underwater Demolition Teams make up one of these groups, retaining their original basic mission. Another group is the Explosive Ordnance Demolition team (EOD) with the mission of handling, defusing, and disposing of munitions and other explosives.

The SEAL teams make up the third group of Navy combat swimmers. SEAL (an acronym for "Sea, Air, Land') 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 trained in SCUBA as well as other swimming and diving techniques. In Viet Nam, SEAL's have been involved in counter-insurgency and guerrilla warfare. The SEAL's also participate in the space program by securing flotation collars to returned space capsules and assisting astronauts during the helicopter pick-up.

Fleet Diving Since World War II 1.3.4 Navy diving has not been limited to tactical combat opera-

Figure 1-23 SEAL divers assist in the recovery of the crew of Apollo 11.

tions, wartime salvage, and submarine sinkings. Fleet diving has become increasingly important and diversified since World War II. A major part of the diving mission is the inspection and repair of naval vessels to minimize downtime and the need for drydocking. Other aspects of fleet diving include the recovery of practice and research torpedoes, installation and repair of underwater electronic arrays, underwater construction, and location and recovery of the remains of aircraft. Ship sinkings and beachings caused by storm damage and human error continue to demand the fleet's salvage and harbor clearance capabilities in peacetime as well as in war.

Loss Of The Thresher 1.3.5 Just as the loss of the F-4, S-51, S-4, and the sinking of the SQUALUS caused a deepened concern regarding Navy diving in the 1920's and 1930's, a submarine disaster of major proportions had a profound effect on the development of new diving equipment and techniques in the post war period. This was the loss of the nuclear attack submarine USS THRESHER with all of her crew in April, 1963. The submarine sank in 8400 feet of water—a depth beyond the survival limit of the hull and far beyond the capability of any existing rescue apparatus.

An extensive search was mounted to locate the submarine; and, if possible, determine the cause of the sinking. First signs of 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 of the subject 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.

Deep Submergence Systems Project 1.3.6 Direct action on the recommendations of the DSRG came with the formation of the Deep Submergence Systems Project (DSSP) in 1964, and an expanded interest regarding diving and undersea activity throughout the naval service.

Submarine rescue capabilities have been substantially improved with the development of the Deep Submergence Rescue Vehicle (DSRV) which became operational in 1972. This deep-diving craft is air-transportable, highly instrumented, and capable of rescue to a depth of 5000 feet.

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.

Navy Saturation Diving 1.3.7 The U.S. Navy has developed and proved saturation diving techniques in its SEALAB series (previously described in this chapter), as well as in on-going programs of research and development at the Experimental Diving Unit in Washington, D.C. and many institutional and commercial hyperbaric facilities. In addition, saturation diving using Deep Diving Systems is now a proven capability.

The basic operation of a deep-diving system is discussed on page 1-12. These systems are ideally suited to the requirements of fleet diving, since they can be mounted on board ship and provide wide margins of safety, mobility, flexibility, and economy in operations.

The Navy developed two types of Deep Diving Systems (DDS). DDS-MK 1 supports two 2-man teams of divers through a 14-day mission profile, and can be transported by air or ship. The DDS-MK1 system has been used in trial dives to 850 feet. The DDS-MK 2, designed for saturation diving, supports two 4-man teams for an extended mission time. DDS-MK 2 is being installed as part of the basic equipment of the new ASR-21 class of submarine rescue ships and holds the current record for open-sea saturation diving—1010 feet.

Recent Developments 1.3.8 The third area of major technological effort has been the development of new equipment for Navy divers; the establishment of special saturation diving tables; and the creation of criteria for the selection and training of saturation divers.

Figure 1-24 Personnel Transfer Capsule of the Navy's Deep Diving System MK 1.

Among the recent types of diver equipment are two models of advanced underwater breathing apparatus. The Mark 10 apparatus, used in both a tethered and free-swimmer mode, is a closed-circuit mixed gas system which uses electronic sensors to control the feed of make-up oxygen from an auxiliary supply tank. The Mark 11 is a semiclosed system designed for use in connection with the Personnel Transfer Capsule (PTC) of the Deep Diving System. The unit is tethered to a PTC by an umbilical which provides it with communications, breathing gas, and heat.

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 really changed. Specific missions are occasionally different, and some new ones have been generated; but the needs of national defense, of commerce, and science continue to provide the underlying basis for the development of diving.

What has changed, and continues to change radically, is diving technology.

Each man who prepares for a dive has the opportunity and obligation to take with him the knowledge of his predecessors which was often gained through difficult and dangerous experience. The modern diver must have a broad understanding of the physical properties of the undersea environment. He must have a detailed knowledge of his own body, and how it will act under the conditions of that environment. And, the diver must learn how to adapt to these conditions so that he can successfully carry out his mission, whatever it may be.

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

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

CHAPTER TWO

UNDERWATER PHYSICS

Man readily functions within the narrow atmospheric "envelope" present at the earth's surface and is seldom concerned with his requirements for survival. Once outside the boundaries of the "envelope," however, the environment is hostile, and his existence is dependent upon his ability to counteract the forces which threaten him. If he is to function safely, a diver must understand the characteristics of the subsea environment and the techniques required to modify its effects.

To accomplish this, he must gain a basic knowledge of physics—the science of matter and energy and their interactions.

THE PHYSICAL WORLD 2.1

Matter—the substance of which the universe is composed—and energy—the forces which work upon and within that substance—have properties and interrelationships which form the foundation of the study of underwater physics. Of particular importance to the diver is a specific knowledge of the behavior of gases, the principles of buoyancy and the properties of heat, light, and sound underwater (Figure 2-1).

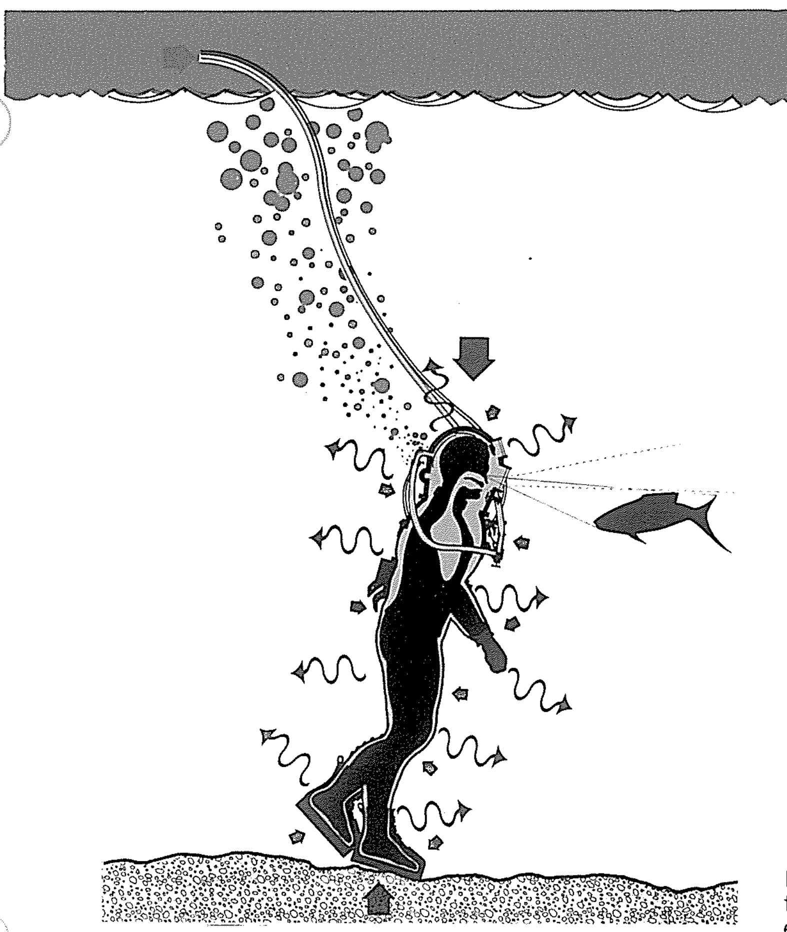


Figure 2-1 The physical forces affecting a diver

Matter 2.1.1 Scientists have identified 109 separate varieties of matter, or elements, that make up the "physical" world. An element is the simplest form of matter which exhibits distinct physical and chemical properties, and cannot be broken up into other, more basic forms by chemical means. About a dozen of these are so rare that they may not even occur in nature—the only samples have all been produced in laboratories. Nonetheless, they stand as elements, each having properties unlike those of any other element.

Elements are made up of atoms, which are so infinitesimally small that it would take more than a million of them, laid side by side, to match the thickness of this page. Atoms can be broken down into smaller particles—electrons, neutrons and protons—but the atom is the smallest particle of matter which carries the specific properties of an element. The various elements combine to form all of the rest of the 4 million-odd substances known to man.

As the atoms group together, they form molecules, which usually exhibit different properties than any of the contributing atoms. For example, when two hydrogen atoms (symbol: H) combine with one oxygen atom (symbol: O) to form water (H_2O), a radically new substance is formed. Graphically:

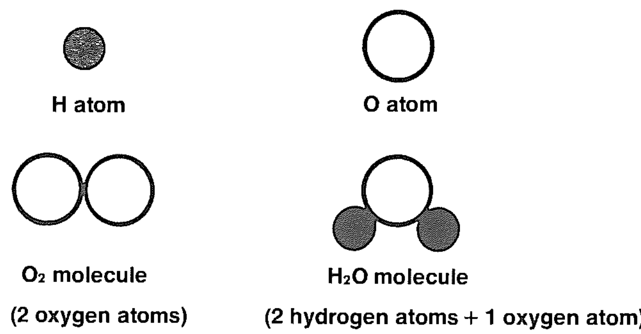


Figure 2-2 Above, two similar oxygen atoms combine to form an oxygen molecule while the atoms of two different elements, hydrogen and oxygen, combine to form a water molecule.

Some atoms are active and try to combine with almost everything they come near. Other atoms are **inert**, and do not naturally combine with other substances. The presence of inert elements in breathing mixtures is of particular importance in diving.

THE THREE STATES OF MATTER 2.1.1.1 Any element or any substance produced by the joining of atoms can exist in one of three natural forms—as a **solid**, **liquid** or gas.

A **solid** has definite shape, weight and volume. **Liquids** have definite volume and weight, but they take the shape of a container, whether it be a soup bowl or the bed of an ocean. Gases have definite weight and occupy space, but lack definite volume or shape (Figure 2-3). A gas will expand indefinitely to fill a container, a room—or, if completely unconfined, will spread continuously through the atmosphere. Gases and liquids are collectively referred to as **fluids**.

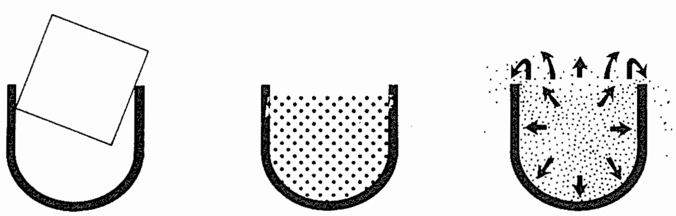


Figure 2-3 Solid, Liquid, Gas

Whether a particular substance exists as a solid, liquid or gas depends principally upon temperature and partially upon pressure (Figure 2-4). In the solid state—coolest of the three—the molecules are rigidly aligned in essentially fixed patterns. They do move, but their action is rather like a constant vibration. As temperature increases, the molecules increase their motion, slip apart from each other and mill around. The solid has melted to become a liquid. Further increases in temperature causes more molecular motion. As heat is added, a few of the molecules will spontaneously leave the surface of the liquid and become a gas; and by the time the boiling point of the substance is reached, the molecules are escaping in all directions at an average speed of 1,000 miles per hour. When this happens, the liquid is quickly transformed into a gas.

Lowering the temperature will reverse the sequence. As the molecules of gas cool, their motion is reduced. The gas condenses and becomes a liquid. Further down the temperature scale, the liquid will reach the freezing point and once again pass into the solid state. The cycle is complete.

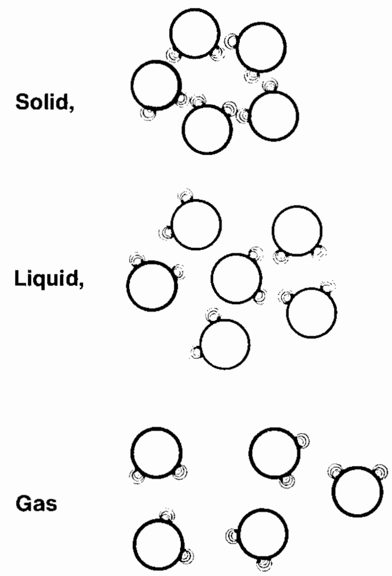


Figure 2-4 The molecular arrangement in the 3 states of matter, Solid, Liquid, Gas

Energy 2.1.2 The concepts of work and energy are closely interrelated and constitute the second major factor in the physical world. **Work** is defined as the application of a force through a distance. It is a force measured in pounds or kilograms which lifts, pulls, or pushes an object through a specific distance such as feet or meters. Work may be applied in numerous ways from propelling an automobile to the creation of atomic particles. The rate at which work is performed is referred to as power.

Energy is the capacity to do work. The Law of the Conservation of Energy, formulated in the 1840's, states that energy in the universe can neither be created nor destroyed. Energy can be changed, however, from one form to another as seen in Figure 2-5. Six basic forms of energy exist—mechanical, heat, light, chemical, electrical and nuclear. From these forms come the numerous energy phenomenon noted in everyday life, e.g., motive force, weather, tides, sound, cold and warmth.

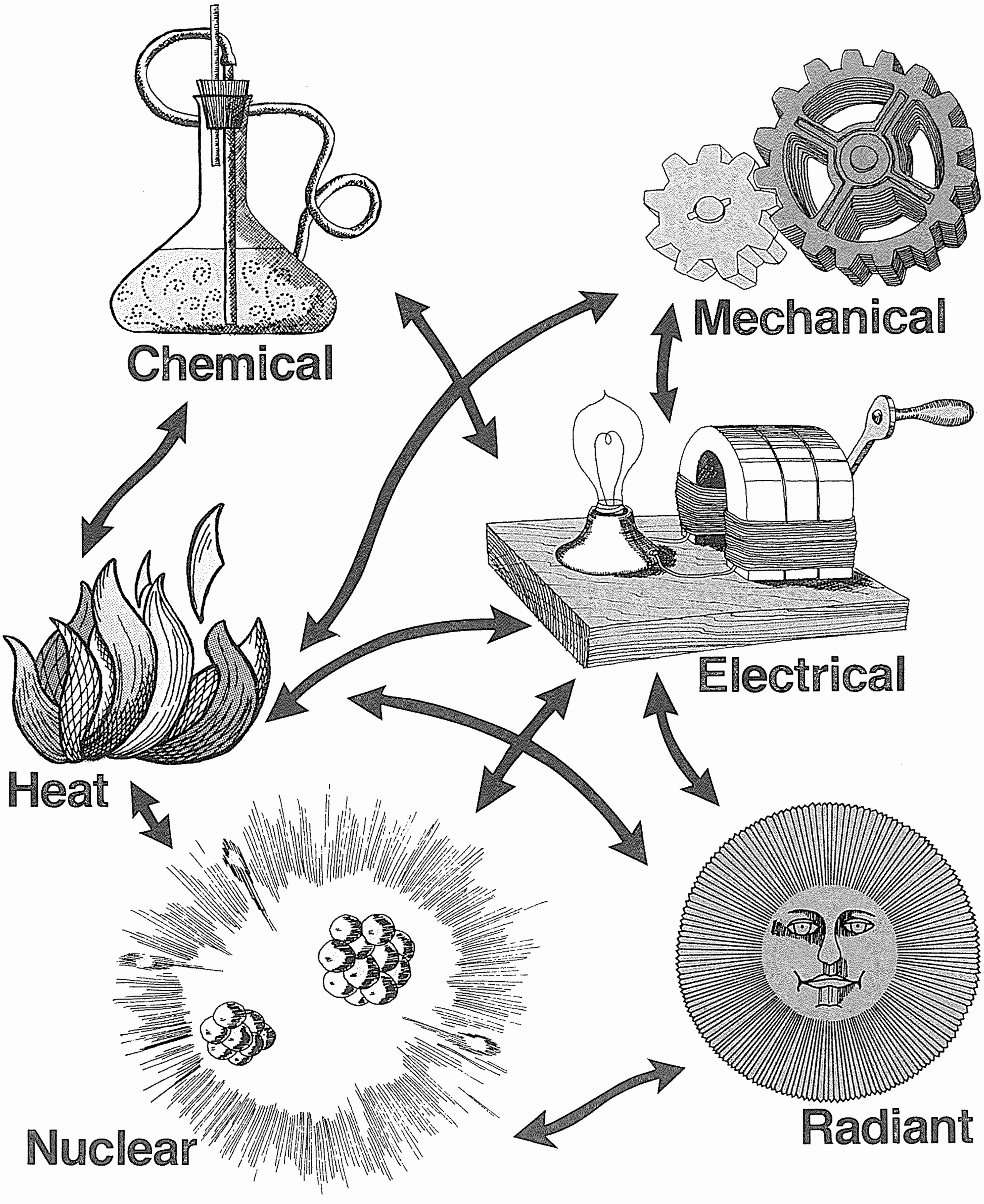


Figure 2-5 The six forms of energy and their interchangability

THE SIX FORMS OF ENERGY 2.1.2.1

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

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

Light—or more properly radiant energy—is energy in the form of waves of electromagnetic radiation. Light energy from the sun provides the sustenance of green plants upon which all animal life, including man, depends for food.

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

Electrical—is energy associated with the presence of electrons (negative particles) or protons (positive particles). Both permanent magnets and storage batteries are typical examples of stored (potential) electrical energy.

Nuclear—or atomic energy is the force which holds the fundamental particles of the nucleus of atoms together. A nuclear powerplant functions by the breakdown of heavy nuclei into lighter nuclei (fission) with an associated release of vast quantities of heat energy in a controlled manner to generate steam.

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

UNITS OF MEASUREMENT 2.2

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

Metric & English System Comparison 2.2.1 Two systems of measurement of force, length, and time are in wide use throughout the world—English and metric. The English system based upon the pound, foot, and second is commonly used in the United States but is being replaced throughout the rest of the world with the metric system. The metric system, originally developed in continental Europe, employs the kilogram, meter, and second as fundamental units of measure.

Metric System The metric system is so widely used, particularly in scientific work, that a diver sooner or later will come in contact with it. The metric system has an advantage in that all its units are so related that it is not necessary to use calculations when changing from one metric unit to another. This system is based on decimals, as is the American system of money. An American can express a sum of money either in dollars or in cents simply by moving the decimal point. In the same way, the metric system changes one of its units of measurement to another by moving the decimal point, rather than by the lengthy calculations necessary in the English system. Conversion from one system to another may be readily accomplished using the conversion factors in Appendix A.

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

1 meter = 100 centimeters (cm)
= 1,000 millimeters (mm)

1 millimeter= 0.10 (one-tenth) centimeter
= 0.001 (one-thousandth) meter

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

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

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

Volume or Capacity—Volumes are expressed as units of length cubed. Conversion of volumes from one metric unit to another requires only moving the decimal point three times as many places as in converting units of length. For example, 1,662 cubic millimeters equals 1.662 cubic centimeters. (To convert cubic inches to cubic feet, you would have to divide by 1,728 (12x12x12).) In addition to cubic feet the U. S. system also uses other units of volume or capacity. No simple relationship exists between these units of volume and the cubic measurements, and consequently calculations involve the uses of numerous conversion factors. The metric system uses the liter (about the same as a quart) for similar purposes, but a liter equals 1,000 cubic centimeters (cc) or 0.001 cubic meter (m^3), and conversion is greatly simplified.

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

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

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

Pressure—The standard metric unit of pressure is the Newton per square meter (N/m^2). However, the most commonly used metric unit of pressure is kilograms per square centimeter (Kg/cm^2). Another commonly encountered metric pressure unit is millimeters of mercury (mmHg). This unit of measurement is based upon the pressure exerted by a column of mercury one millimeter high.

1 Kg/cm^2 = 1,000 g/cm^2
= 1,000 cm H_2O
= 10 meters H_2O
= (approx.) 1 atm

1 mm Hg = 1.35 g/cm^2
= 13.5 Kg/m^2
= 133.32 N/m^2
= $\frac{1}{760}$ atm

1 Bar = 1.02 Kg/cm^2
= 0.99 atm
= 750 mm Hg
= 10.21 meters H_2O

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

Conversion from one temperature scale to another may be accomplished by the algebraic solution of the following equations:

To convert from Fahrenheit to Celsius—

$$°C = \frac{5}{9} \times (°F - 32)$$

To convert from Celsius to Fahrenheit—

$$°F = (\frac{9}{5} \times °C) + 32$$

Convenient temperature conversion charts will be found in Appendix A.

Absolute temperature values are used when making certain types of calculations, such as when employing the ideal gas laws. The absolute temperature scales are based upon absolute zero—the lowest temperature that could possibly be reached—at which all molecular motion would cease. On the Fahrenheit scale this temperature is −459.72° F; in Celsius it is −273.13°C. These numbers are normally rounded off to −460°F and −273°C. A comparison of the four temperature scales will be noted in Figure 2-6.

To convert from Fahrenheit to absolute temperature (called degrees Rankine—°R)—

$$°R = °F + 460$$

To convert from Celsius to absolute temperature (called degrees Kelvin—°K)—

$$°K = °C + 273$$

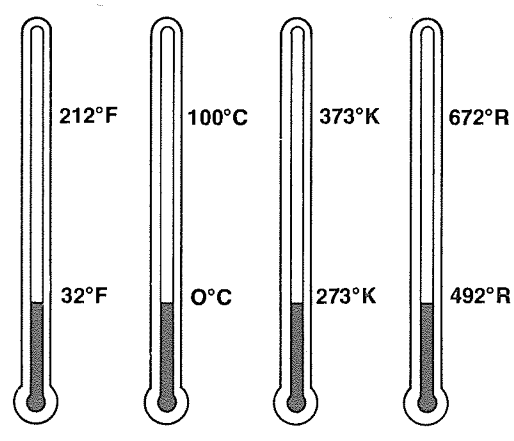


Figure 2-6 Fahrenheit, Celsius, Kelvin and Rankin temperature scales showing the freezing and boiling points of water

Pressure in Diving 2.3

Pressure can be simply defined as a force (or weight) acting upon a particular area of matter. It is typically measured in pounds per square inch in the English system (abbreviated as "psi"), and kilograms per square centimeter (Kg/cm^2) in the metric system.

Under the sea, pressure is a result of two factors. First, the weight of the water surrounding the diver. And, second, the weight of the atmosphere over that water.

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

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

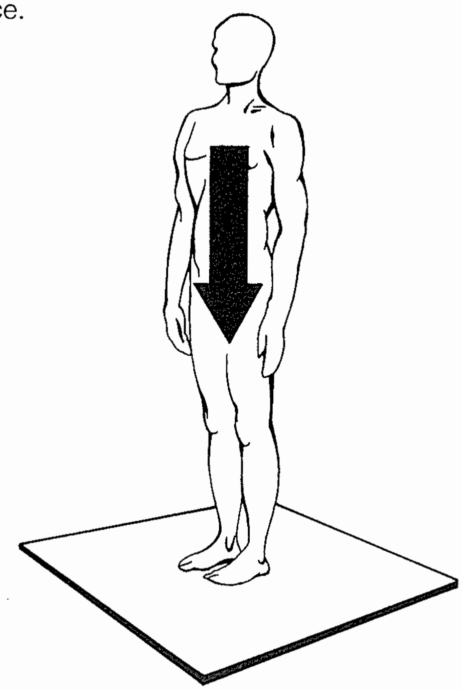


Figure 2-7 An average man weighs about 170 lbs and this weight is distributed over an area of approximately 90 sq. inches giving an average pressure of 1.89 psi. The platform with an area of 1296 sq. in. distributes his weight with an average pressure of 0.131 psi.

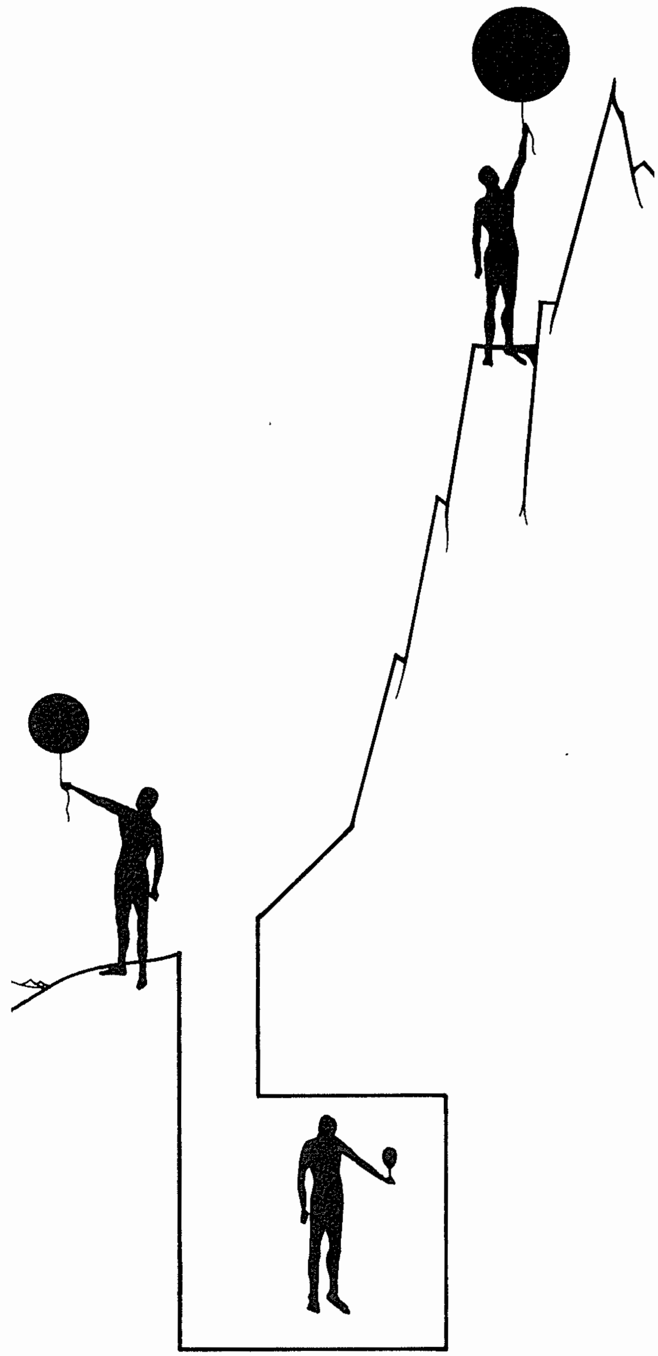


Figure 2-8 At sea level the balloon has a given volume with respect to temperature and atmospheric pressure. As we descend into the mine shaft the volume of the balloon decreases due to increased atmospheric pressure. Conversely as we ascend the mountain, the balloon expands as the atmospheric pressure decreases.

The Weight of the Atmosphere 2.3.1 The early scientists who first discovered gases did so through a series of experiments which quite literally started with "nothing" and ended up with "something." The Greeks of antiquity were satisfied that air had substance even though it could not be seen, touched or stored on the shelf like a block of wood or bottle of water. Air—as wind or exhaled breath—could be felt, and air had sufficient substance (even though unseen) to block the passage of water if trapped in a tube. This can be easily demonstrated as in Figure 2-9.

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

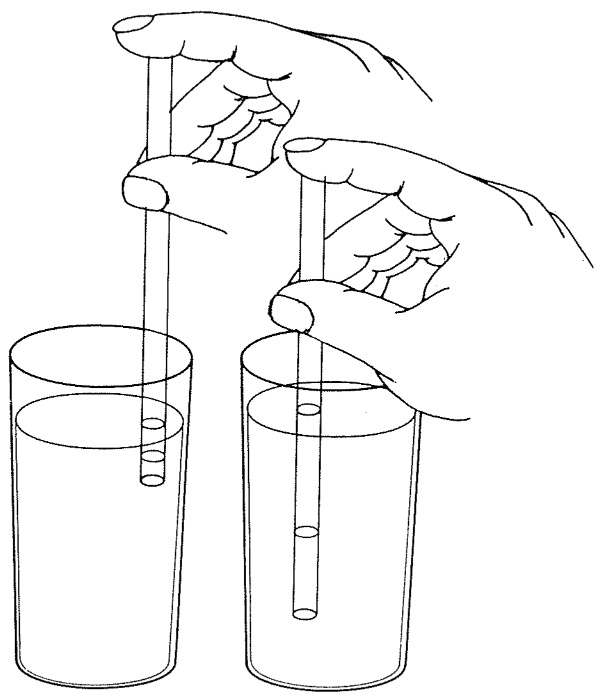


Figure 2-9 Put a finger over one end of a soda straw and push the other end down into a glass of water. No matter how far down you push the straw, the water will not rise in the straw to match the water level in the glass.

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

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

Toricelli substituted mercury (13.6 times heavier) for water to reduce the size of his apparatus. He took a four-foot glass tube, sealed at one end, and filled it completely with mercury. With a finger over the open end, he turned the tube upside down and submerged the covered end in a bowl also filled with mercury. When he took away his finger, the mercury in the tube dropped—but not all of the way down. The falling stopped when about 30 inches of mercury (760 mmHg) were still in the tube. Above the mercury, there was now a vacuum created by the falling liquid.

Toricelli was thereby able to state that the weight of the air, pressing on the mercury in the bowl, was sufficient to offset the weight of a 30-inch (760 mmHg) column of mercury.

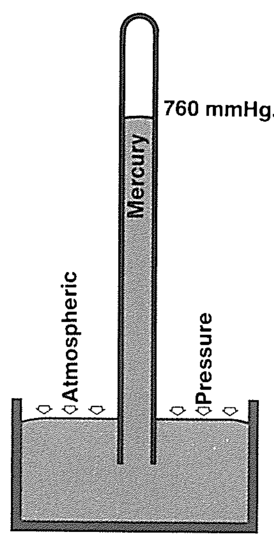


Figure 2-10 Toricelli's Barometer

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

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

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

UNITS OF PRESSURE 2.3.1.1 Since atmospheric pressure is universally applied, it does not register on the pressure gage, for example, of a tank of compressed air. The air in that tank, the tank, and the gage itself are already under a base pressure of 1 atm (14.7 psi or 1 Kg/cm^2). The gage measures the pressure difference between the atmosphere and the air in the tank. This reading is called gage pressure; and for most purposes it is sufficient. However, in some applications—and especially in diving—it is often important to include the already-existing "one atmosphere" in the computation. This total pressure is called absolute pressure and is normally expressed in units of "atmospheres." Since the distinction is important, pressure must be identified as either gage or absolute. When the type of pressure is not identified (psi), it refers to gage pressure. Conversion factors for the various units of pressure measurement will be found in Appendix A.

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

atmospheric—usually expressed as 1 Kg/cm^2, 14.7 psia 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 29.92 inches of mercury or 760 millimeters (mmHg)].

gage—which indicates the difference between atmospheric pressure and the pressure being measured.

absolute—which is the total pressure being exerted—that is, gage plus one atomsphere.

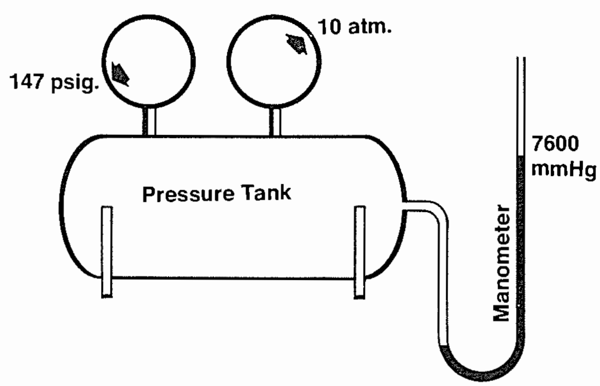


Figure 2-11 Pressure is commonly expressed in atmospheres, pounds per square inch gage and millimeters of mercury.

Liquid Pressure 2.3.2 Certain physical properties of water bring an extra dimension to the study of pressure as it affects a diver. With a gas, pressure is increased by pumping more molecules into a container, by reducing the volume, or by heating the gas. These actions will not have the same effect upon a liquid. Water—like all liquids—is virtually incompressible and can not be squeezed into a smaller container. Any outside pressure applied to water will simply spread throughout the liquid—equally and in all directions.

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

Recalling the findings of Toricelli and Pascal, it is obvious that the pressure of sea water at a depth of 33 feet will be equal to one atmosphere. The absolute pressure, which is a combination of atmospheric and water pressure for that depth, will be 2 atmospheres. For every additional 33 feet of depth, another atmosphere of pressure (14.7 psi) will be encountered. Thus, at 99 feet, the absolute pressure will be equal to four atmospheres.

Surface (one atmosphere)		1 atm.
First 33 feet (gage)	+	1 atm.
Absolute Pressure	=	2 atm.
Second 33 feet (gage)	+	1 atm.
Third 33 feet (gage)	+	1 atm.
Absolute Pressure at 99 feet	=	4 atm.

This change in pressure with depth is so regular and so pronounced that the feet of a man standing under water will be receiving pressure that is almost three pounds per square inch greater than that received at his head.

Buoyancy 2.3.3 The force that makes objects float—whether pieces of cork or ships with steel hulls—is known as buoyancy. It was first defined by the Greek mathematician Archimedes, who established that any object wholly or partly immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object. This is known as Archimedes' Principle, and it applies to all objects and all fluids.

The buoyant force of the fluid depends upon its density (weight per unit volume). Salt water, with a density of 64 pounds per cubic foot (1.025 g/cc) has a slightly greater buoyant force than fresh water, which has a density of 62.4 pounds per cubic foot (1.0 g/cc). This is why it is noticeably easier for a swimmer to float in the ocean than in a lake—his body displaces a smaller volume of seawater than it would displace in freshwater; therefore, a greater percentage of his body will remain out of the water.

The tendency of a substance to float—or not to float—in water is indicated by its specific gravity. For a solid or a liquid, this is a number assigned on the basis of the ratio of the density of the substance to the density of fresh water. Water is given a specific gravity of 1.0. Cork, which has one-fourth the density of water (15 pounds per cubic foot or 0.24 g/cc) has a specific gravity of 0.24. The specific gravity of gases is compared with the density of air at 59°F (15°C) at 1 atm. abs.

The human body has a specific gravity of approximately 1.0. This will vary slightly from one person to the next—the average man will experience little difficulty in floating in water, a fat person will readily float, and a person with a thin, lean body may experience trouble floating. The natural buoyancy of any swimmer can temporarily be increased by his taking a deep breath of air. This inflates the chest cavity, displacing more water and thereby increasing the upward, buoyant force.

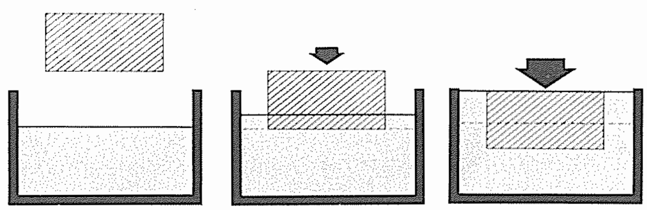


Figure 2-12 Buoyancy: As a block is immersed in a liquid, it displaces a volume of liquid equal to its own volume. The weight of the volume of liquid displaced is equal to the buoyant force on the block.

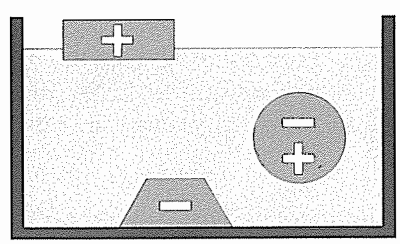


Figure 2-13 Three terms are frequently used in diving to describe different stages of buoyancy; **positive buoyancy,** indicating a tendency to float, **negative buoyancy** which connotes a tendency to sink, and **neutral buoyancy** which reflects a condition of balance wherein an object will tend to neither rise nor sink but will remain suspended an any particular level.

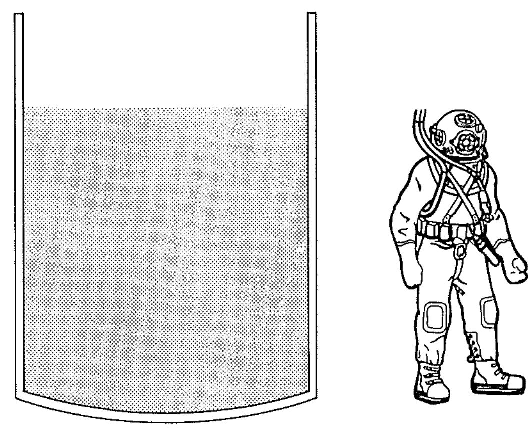
A diver can vary his buoyancy in several ways. By adding weights to his gear, he can cause himself to sink. If wearing surface-supplied diving dress, he can increase or decrease the amount of air in the suit, thus changing his displacement and thereby his buoyancy. Minor changes in his volume can produce a significant change in buoyancy. Applying the principle of Archimedes, it is readily determined that one-half cubic foot (14.2 liters) of added displacement will provide a lifting force of 32 pounds (14.5 kg).

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

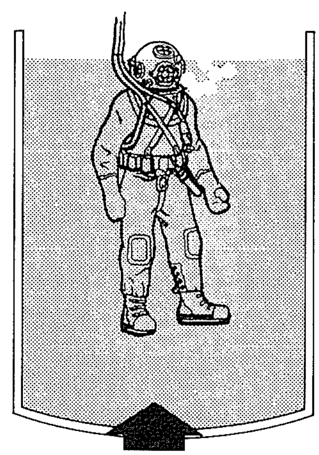
The air in a diving suit—or the air in the lungs of a swimmer holding his breath—will be compressed or will expand depending upon depth. For the swimmer, it means that, as the air is compressed he will not displace as much water and will lose buoyancy as he goes deeper in the water. At a depth of approximately 15-20 feet (5-6 meters), a breath-holding diver will reach a state of neutral buoyancy and below that level, he will tend to sink.

For the hard-hat diver, the changing displacement means that he must control his inlet and exhaust to counter the changes, (Figure 2-14). For example: if in ascending, he does not vent the air sufficiently to offset the increasing volume in his suit, his situation will become increasingly critical. The faster he rises, the more the air expands, causing an even faster ascent until he pops to the surface, out of control and with possibly serious consequences from decompression sickness or from colliding with the bottom of his ship or other surface object. This condition is known as "blowing up" and is covered in more detail in Chapter Eight.

A condition opposite to "blowing up" can also pose a problem for the diver. That is, as he descends and the air in his suit becomes compressed, he displaces less water and sinks faster. This can lead to the same sort of chain reaction and to the danger of squeeze (Chapter Eight) unless he adds sufficient air to keep his displacement at a balanced value.



Weight of diver, helmet and dress = 384 lbs.



416 – 384 = 32 lbs positive

Figure 2-14 Buoyancy in Deep-Sea Diving
A diver, with his helmet and dress, weighs 384 pounds. If he inflates his dress so that he displaces 6.5 cubic feet of water, he will be buoyed up by a force equal to the weight of 6.5 cubic feet of water. Since sea water weighs 64 pounds per cubic foot, the buoyant force acting on this diver would be $6.5 \times 64 = 416$ lbs. This force is 32 pounds (416 – 384) more than his total weight and consequently the diver would be positively buoyant and float with half a cubic foot of his volume out of water. The volume of water displaced would be 6 cubic feet, the weight of which ($6 \times 64 = 384$ pounds) would just equal his own weight. If the dive were conducted in lower density (62.4 pounds per cubic foot) freshwater, the diver would be less buoyant ($6.5 \times 62.4 - 384 = 21.6$ pounds). He would float with 0.35 cubic foot $\frac{21.6}{62.4}$ above the surface.

GASES IN DIVING 2.4

Gases are the most elusive and intangible of substances, but a knowledge of the properties and behavior of gases—especially those used for breathing—is of vital importance to a diver.

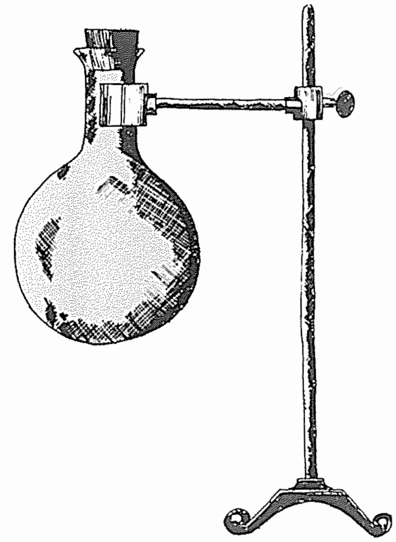
The Group of Diving Gases 2.4.1 There is a special group of gases encountered in diving and the majority of the members of this group—eight in number—are normally found, in varying quantities, in the atmosphere (Figure 2-15). These gases are oxygen, nitrogen, helium, hydrogen, neon, carbon dioxide, carbon monoxide, and water vapor. They are not the only gases that may occur in the atmosphere, nor are they the only gases which have been used in diving, but the others—argon, krypton, and xenon—have all been rejected for diving use for various reasons.

While these gases are discussed separately, the gases themselves are almost always used in some mixture—air itself 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.

THE COMPOSITION OF DRY AIR

COMPONENT	PERCENT BY VOLUME
Nitrogen	78.084
Argon (Inert)	0.934
Oxygen	20.946
Carbon Dioxide	0.033
Rare Gases: Neon, Helium, Krypton, Hydrogen, Xenon, Radon, Carbon Monoxide	0.003
Commonly Simplified	
Nitrogen	79
Oxygen	21

Figure 2-15 The Composition of Dry Air



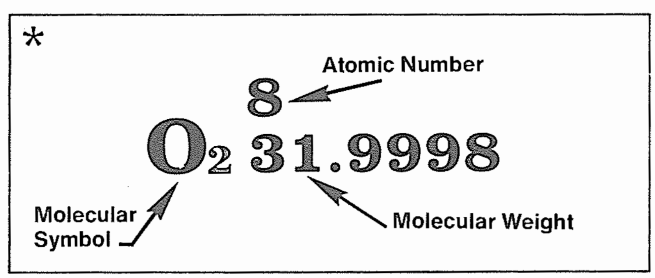
8

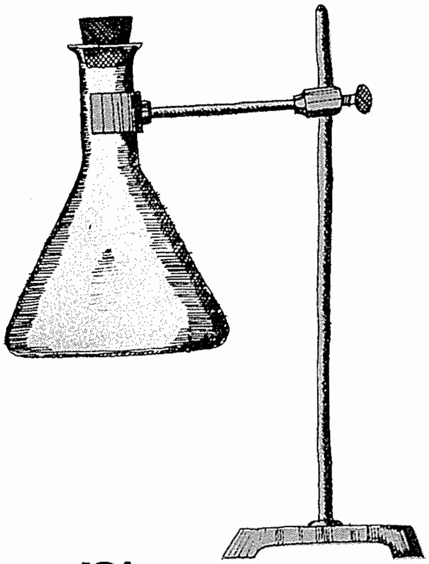
O_2 31.9998*

OXYGEN

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

It is the oxygen in the air we breathe—and only the oxygen—that is actually used by the body. The other 79% of the air serves to dilute and carry the oxygen. Pure 100% oxygen is often used for breathing in hospitals and in aircraft. Sometimes 100% oxygen is used in shallow diving operations. However, if a man breathes pure oxygen under pressure, he may experience the serious problems of oxygen poisoning. (See Chapter Three, "Diving Physiology.")





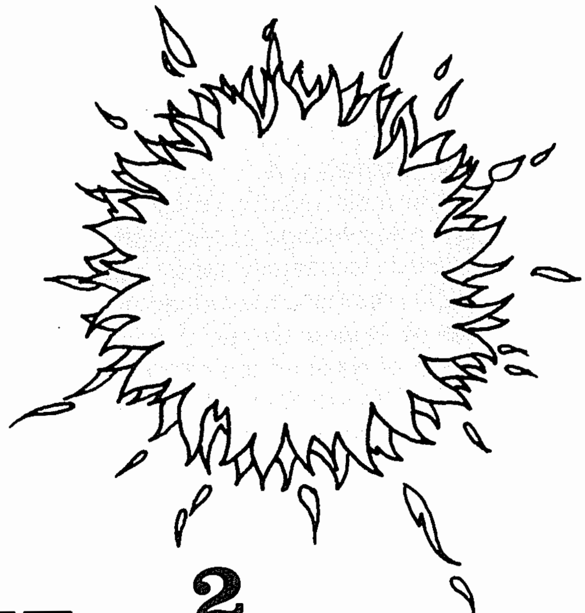
N_2 7 28.0134

NITROGEN

Like oxygen, nitrogen is colorless, odorless and tasteless, and is a component of all living organisms. However, unlike oxygen it will not support life or aid combustion, and it does not easily combine with other elements. Nitrogen in the air is inert in the free state and is essentially a "carrier" for the oxygen. For divers, the nitrogen may be considered to dilute the oxygen.

Nitrogen is not the only gas which can be used for this purpose and, under some conditions, it has severe disadvantages 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 in deep diving operations below a specified depth.



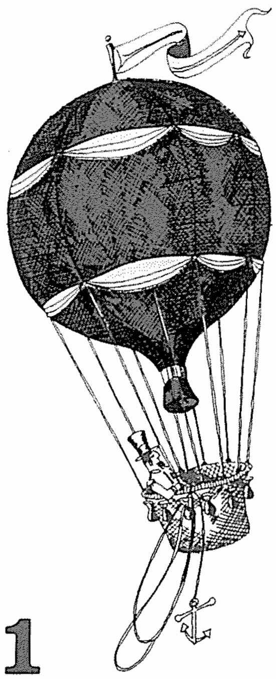
He 2 4.0026

HELIUM

Helium is also a colorless, odorless and tasteless gas but it is monatomic; that is it exists as a single atom in its free state. It is almost totally inert—so inert that it does not even combine with itself. It is also virtually insoluble in water.

Helium is a rare element, found in the air only as a trace (about 1/200,000). It was first discovered in 1868 through spectrographic analysis of the sun (hence the name, from the Greek *helios,* meaning "sun") before it was ever isolated on earth, in 1895. Since helium is seven times lighter than air, its primary use in the early 20th century was for inflation of balloons and dirigibles. Helium coexists with natural gas in certain wells in the southwestern United States, Canada, and the USSR. Separation of the gas from these wells provides the world's supply.

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



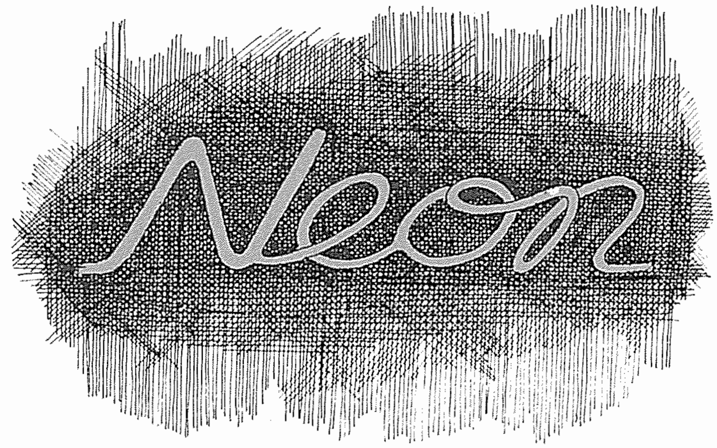
1

H_2 2.01594

HYDROGEN

Hydrogen, also diatomic, colorless, odorless and tasteless is so active that it is rarely found in a free state on earth. It is, however, the most abundant element in the rest of the universe—the sun and stars are almost pure hydrogen.

Hydrogen is the lightest of all elements and for 150 years was used extensively to give the lift to lighter-than-air craft. It is violently explosive when mixed with air in proportions that include a presence of more than 5.3% oxygen. The flaming crash of the German dirigible airship HINDENBURG in 1937 (at the Naval Air Station in Lakehurst, New Jersey) put an effective end to the general use of hydrogen in lighter-than-air ships. Hydrogen has been used in diving (replacing nitrogen for the same reasons as helium), but the hazards have limited this to little more than experimentation. Because helium has been so readily available in the United States, the U. S. Navy has never had cause to use hydrogen for diving.



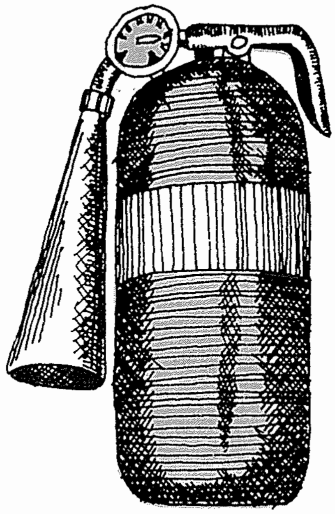
10

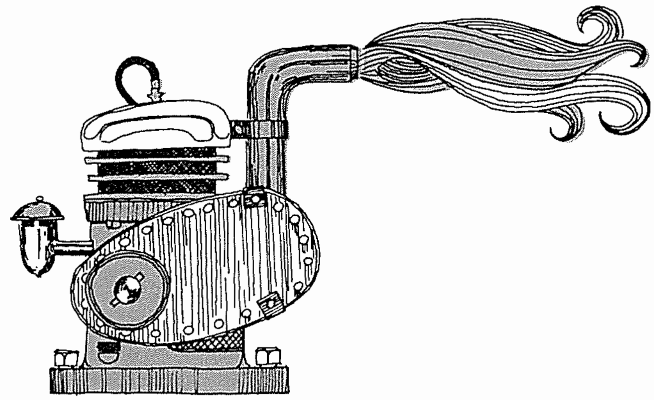
Ne 20.183

NEON

Neon is inert, monatomic, colorless, odorless and tasteless—and is found in minute quantities in the atmosphere. Neon is a good conductor of electricity when held at very low pressure and glows with a distinctive orange-red color. Because of this it is most commonly used in making illuminated signs and advertising displays.

It is a heavy gas, but does not exhibit the narcotic properties of nitrogen when used as a breathing medium. Since 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.





CO_2 44.0103

CARBON DIOXIDE

Carbon dioxide is colorless, odorless and tasteless when found in small percentages in the air. In greater concentrations it has an acid taste and odor. It is a chemically active gas which is commonly observed as bubbles in soda water and champagne. It also causes the rising of bread dough, and is widely used as an extinguishing agent in fire extinguishers.

Carbon dioxide is a natural by-product of the respiration of animals and humans (among other sources) formed by the oxidation of carbon in the body to produce energy. It occurs in the atmosphere as approximately .03% of the total. For divers, the two major concerns with CO_2 are control of the quantity in the breathing supply, and removal of the "exhaust" after breathing.

In high concentrations the gas can be extremely toxic. Severe problems may arise for divers who use closed-circuit and semiclosed breathing systems, if the system fails to dispose of the excess CO_2.

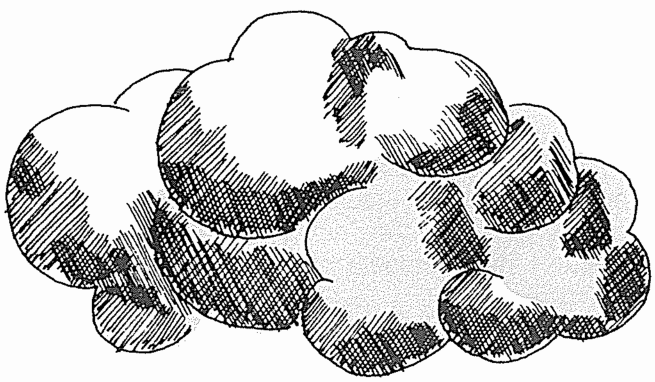
CO 28.0106

CARBON MONOXIDE

Carbon monoxide does not naturally occur in any quantity in the air and could almost be considered to be "man-made." It is the result of incomplete combustion of fuels and is most commonly found in the exhaust of internal combustion engines. It is highly poisonous to man, and, since it is colorless, odorless and tasteless, it is difficult to detect. Carbon monoxide is chemically highly active and seriously interferes with the ability of the blood to carry oxygen.

The first symptom of CO poisoning is usually drowsiness accompanied with a headache; this is followed by a loss of consciousness and, unless corrected in time, can result in death.

A typical carbon monoxide problem for divers is contamination of the air supply from improper placement of the compressor engine exhaust too close to the pump intake. In such a situation, the exhaust gases are sucked in with the air and sent on to the diver—often with disastrous results.



H_2O 18.0153

WATER VAPOR

Air always contains some percentage of water vapor which must be considered as a gas. This is the "humidity" that sometimes makes the weather—especially hot weather—uncomfortable.

A diver must have an understanding of humidity because too much water vapor in the air supply can cause problems ranging from a fogged face-plate, to a frozen air-line, to chilling of his body. Too little moisture can also cause other problems such as irritated sinuses or throat and dried-out gaskets in pumps and air-lines. Because of its unique physical characteristics encountered during diving operations, Section 2.4.5 provides a detailed presentation on water vapor.

Kinetic Theory of Gases 2.4.2 On the surface of the earth the constancy of the atmosphere's pressure and composition tend to be accepted without concern. To the diver, however, the nature of the high pressure, or hyperbaric, gaseous environment assumes great importance. The basic explanation of the behavior of gases under all variations of temperature and pressure is known as the kinetic theory of gases.

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

If the gas is confined at atmospheric pressure, each square inch of each side of the container will be struck by about 2,000,000,000,000,000,000,000,000 molecules per second. These molecules are infinitesimal, and individually have little impact. However, because they act together in such large numbers, and at such high speed, they produce a measurable force.

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

The kinetic theory of gases, therefore, states—The kinetic energy of any gas at a given temperature is the same as the kinetic energy of any other gas at the same temperature.

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

*For simplicity, the terms "mass" and "weight" will be used interchangeably in this manual. In the science of physics many laws are based upon the **absolute** measurement of quantity of matter (mass) which takes into consideration changes in the gravitational field. The term "weight" denotes the apparent quantity of matter resulting from measurement under the prevailing gravitational field.

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

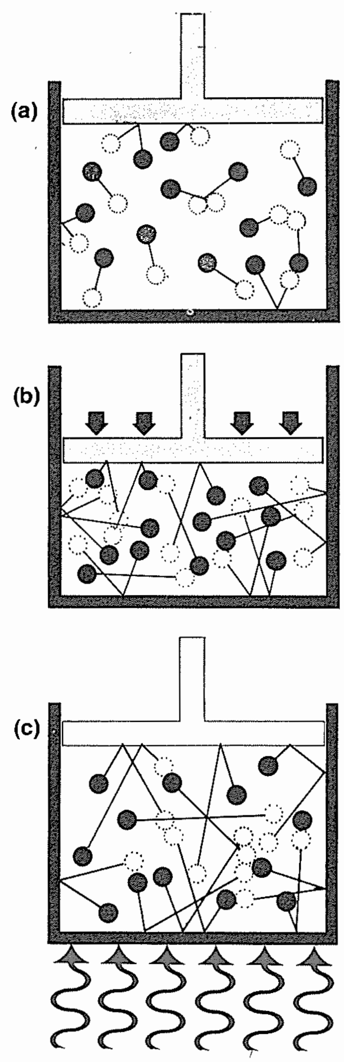


Figure 2-16 The kinetic energy of the molecules inside the container in (a) above produces a constant pressure on the internal surfaces. As the container volume is decreased (b), the molecules per unit volume (density) increase and so does the pressure. As the energy level of the molecule increases from the addition of thermal energy (heat), so does the pressure (c).

Gas Laws 2.4.3 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—such as an increase in temperature—must result in some measurable change in the other factors. Further, the theory indicates that the kinetic behavior of any one gas will be the same for all gases or mixtures of gases. Consequently, basic rules have been established to help predict the changes which will be reflected in temperature, pressure or volume as the conditions of the operating environment are changed.

For example, a diver needs to know what effect the changing pressures will have upon the air in his suit and in his lungs as he moves up and down in the water. He must be able to determine the capability of an air compressor to deliver an adequate supply of air to a proposed operating depth. He needs to be able to interpret the reading on the pressure gage of his tanks under varying conditions of temperature and pressure. The answers to such questions are calculated through the use of a set of rules called the "gas laws."

The gas laws of direct concern to divers are:

Boyle's Law Charles' Law Dalton's Law

An important note:
In working with the gas laws, all pressure is **absolute pressure** (adding the ever-present one atmosphere), all temperature is **absolute temperature,** and all units used in the equations should be in one system of units, **English or Metric.**

BOYLE'S LAW 2.4.3.1 In 1660, having heard of the discoveries of Toricelli and Pascal, Robert Boyle set out to determine what would happen to a given quantity of confined air if the pressure were changed.

Boyle took a J-shaped tube of glass and sealed the short leg. He then poured mercury into the longer leg until the amount of mercury in each leg was equal. At that point, he reasoned that the pressure of the air trapped in the closed end of the tube must be equal to the pressure of the atmosphere acting on the mercury in the longer, open end. Boyle then added more mercury until he could see that the volume of air trapped in the short leg was cut in half. This took an added 30 inches (760 mmHg) of mercury, which meant that he had added an amount equal to atmospheric pressure and had thus doubled the pressure on the trapped gas.

His demonstration showed that **the pressure and volume of a gas are inversely related**—that is, the higher the pressure, the smaller the volume, and vice-versa. Expressed as a formula, Boyle's Law is—

$$PV = C$$

where P = absolute pressure, V = volume and C = a constant.

To illustrate **Boyle's Law:** If a bubble of air (or air in a rubber balloon) of 1 cubic foot is pushed down into the water to a depth of 33 feet, the pressure on the outside of the balloon will have been doubled by the addition of one atmosphere of pressure to the surface pressure. The effect on the volume of the air will be a reduction to one-half the original volume.

Before: $PV = C$

$1 \text{ atm abs} \times 1 \text{ cu ft} = 1$

After: $2 \text{ atm abs} \times V = 1$

$V = 0.5 \text{ cu ft}$

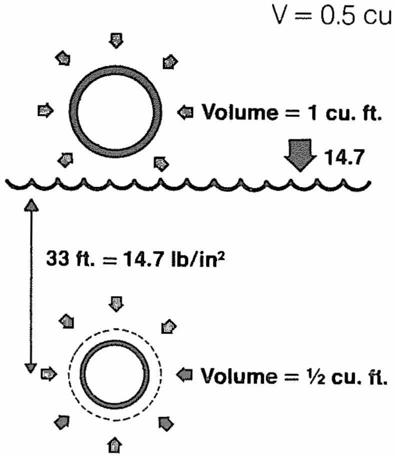


Figure 2-17 Boyle's law; example

If the balloon is released and allowed to rise to the surface, the volume will return to the original amount as the pressure is reduced to one atmosphere.

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

For example: The balloon of air in the previous illustration has been reduced in volume by a full 50% in the change from one atmosphere at the surface to two atmospheres at 33 feet. By using the formula, demonstrate how much that volume will change if the balloon is moved deeper—from 33 feet to 66 feet where the pressure is 3 atmospheres absolute:

At 33 feet: $PV = C$

$2 \times 0.5 = 1$

At 66 feet: $3 \times V = 1$

$V = 1/3, \text{ or } 0.33 \text{ cu ft}$

The change between 33 feet and 66 feet is much less than that between the surface and 33 feet—a change of only 0.17 cu ft compared with 0.5 cu ft. An understanding of this relationship is important to a diver, because it indicates that sudden changes while in shallow water can be more dangerous than an equivalent change of depth while working deeper in the water. Actually, the change in gas volume in the last 33 feet of an ascent would be greater than the change that would occur in rising from a depth of 297 feet to 33 feet:

At 297 feet (10 atm abs):

$PV = C$

$10 \times V = 1$

$V = 1/10, \text{ or } 0.1 \text{ cu ft}$

At 33 feet, the volume is 0.5 cu ft, and at surface, 1 cu ft.

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

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

While you were at 66 ft. breathing normally from your SCUBA, you were in pressure balance with your immediate environment. The absolute pressure at that depth is 3 atmospheres. The regulator on your SCUBA was automatically delivering breathing air at the same pressure, so that the air inside your lungs balanced the outside pressure. Your lungs were at their normal size and capacity, and that last breath just filled them to about 5 liters.

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

If you held your breath in an attempt to contain the air, by the time you reached the surface that lungful of air would have expanded to three times the normal lung capacity. In all probability the overinflation of your lungs would have caused an embolism—a serious medical disorder caused by gas bubbles being forced through the lung tissue into the blood stream. For this reason free-ascent training stresses the continuous blowing off of the expanding air and the dangers of breath-holding.

CHARLES' LAW 2.4.3.2 Boyle had shown that pressure and volume were inversely related. However, since his experiments were conducted at relatively low pressures and at whatever the temperature happened to be on the day of his experiments, they provided no clues as to the influence of temperature. A French scientist, Jacques Charles, found that if the pressure was kept constant—as in some sort of freely-expanding container—the volume of gas would increase as the temperature increased. Conversely, if the volume was restrained in a rigid container, the pressure would increase with the temperature. This is all in accordance with the kinetic theory of gases—higher temperatures, higher molecular speeds.

Charles' Law states that the amount of change in either volume or pressure is directly related to the change in the absolute temperature.

Algebraically:

$$PV = RT \text{ or } \frac{PV}{T} = R$$

Where P = absolute pressure, V = volume, T = absolute temperature, R = a universal constant for all gases.

As an example, if the absolute temperature were doubled, the volume or pressure would also be doubled (depending on the type of container employed).

THE GENERAL GAS LAW 2.4.3.3 Boyle and Charles demonstrated that with a gas—any gas—the factors of temperature, volume and pressure were so interrelated that a change in any of these factors must be balanced by a corresponding change in one or both of the others. Boyle's Law illustrates pressure/volume relationships, and Charles' Law basically describes the effect of temperature changes on pressure and/or volume. The General Gas Law is a convenient combination of these two laws in predicting the behavior of a given quantity of gas when changes may be expected in any or all of the variables.

$$\text{Since } \frac{P_1V_1}{T_1} = K$$

$$\text{and } \frac{P_2V_2}{T_2} = K$$

The formula for the General Gas Law is:

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

The symbols refer as follows:

P_1 = initial pressure (absolute)
V_1 = initial volume
T_1 = initial temperature (absolute)
P_2 = final pressure (absolute)
V_2 = final volume
T_2 = final temperature (absolute)
K = a constant

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

1. There can be only one unknown.
2. If it is known that a value remains unchanged

(such as the volume of an air tank), or that the change in one of the variables will be of little consequence, cancel the value out of both sides of the equation, thus simplifying the computations.

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

Example No. 1—

You are stationed aboard a small salvage vessel operating out of Key West, Florida. Your ship has been given the task of locating and salvaging an LCM landing craft which had been damaged and sunk in a recent exercise.

The ship's fathometer has indicated a sharp rise on the otherwise flat bottom in 130 feet of water, and you are to make an exploratory dive to survey the contact. This first dive will be of short duration, and you will use SCUBA.

As the air tanks of the SCUBA are being charged to a capacity of 1,785 psig, the temperature in the tank has risen to 140°F. From experience in these waters, you know that the temperature at the operating depth will be about 40°F and you want to know what the gage reading will be when you first reach the bottom.

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

P_1 = 1,785 psi (gage) + 14.7 psi (atmospheric)
= 1799.7 psia

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

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

°R = °F + 460°

T_1 = 140° + 460°
= 600°R

T_2 = 40° + 460°
= 500°R

P_2 = Unknown

From the formula (with V eliminated):

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

Rearranging the formula (following standard algebraic procedures) to solve for P_2:

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

Substitute values and solve:

$$P_2 = \frac{1799.7 \text{ psia} \times 500°R}{600°R} = 1{,}499.75 \text{ psia}$$

Adjust P_2 to gage pressure:

1,499.75 psia − 14.7 psi = 1,485.05 psig

Example No. 2—

During your initial dive, you and your buddy diver verify that the depth-finder contact is in fact the LCM. You survey the craft and determine that the damage will require a simple patch. For this job, the Diving Supervisor decides to send down a "hard-hat" diver.

You will act as tender for the dive and while the diver is getting his gear ready, you make a calculation to be certain that the air compressor you plan to use has sufficient capacity to deliver the proper volume of air to the working diver and standby diver at the operating depth and temperature.

The compressor has a suction capacity of 60 cubic feet per minute, and the temperature of the air on the deck of the ship is 80°F. The pressure at working depth is approximately 5 atmospheres absolute. This is derived by dividing the depth (130 feet) by the increment of depth which has a pressure equal to one atmosphere (33 feet) and adding one atmosphere to give absolute pressure. The problem can be solved using either psi values or units of atmosphere, but not both in the same problem, using atmospheres simplifies the arithmetic. The absolute temperatures are 540°R on the surface (80°F + 460°F) and 500°R at depth, as computed in Example No. 1.

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

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

Substitute values and solve:

$$V_2 = \frac{1 \text{ atm} \times 60 \text{ cu. ft. min.} \times 500°R}{5 \text{ atm} \times 540°R}$$

= 11.1 cu ft/min at bottom conditions

Based upon an actual volume (displacement) flow requirement of 4.5 cu ft/min (CHAPTER SIX) for a deep-sea diver, the compressor capacity is sufficient to support two divers (9.0 cu ft) at the 130 foot depth.

Gas Mixtures 2.4.4 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, the only "one" gas which could be used is oxygen—since it is the only one which provides life-support. But, as noted earlier, 100% oxygen is dangerous when breathed at depths greater than 25 feet.

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

DALTON'S LAW 2.4.4.1 Dalton's Law—named for the English scientist who discovered the principle involved—states that:

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—each gas acting as if it alone was present and occupied the total volume.

In other words, "the whole is equal to the sum of its parts" and each part is not affected by any of the other parts. The pressure contributed by any gas in the mixture is proportional to the number of molecules of that gas in the total volume—and the pressure of that gas is called its **partial pressure** (pp), meaning its part of the whole. Dalton's Law is sometimes referred to as "the law of partial pressures."

Stated algebraically:

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

and

$$pp_A = P_{Total} \times \frac{\% \, Vol._A}{100\%}$$

An operational example will best illustrate the use of—and importance—of Dalton's Law.

Continuing with the salvage job off Key West; just before the diver's faceplate is closed he takes a normal breath of air. That breath contains millions of molecules of various gases mixed freely in the atmosphere. The pressure of the gas he has just taken in is normal atmospheric pressure, 1.0 atmosphere absolute.

Since the composition of the air is almost constant, we know that for every 10,000 molecules of gas in that breath, 2,100 will be oxygen, 7,800 will be nitrogen, 97 will be of all the other gases except carbon dioxide, which will comprise approximately 3 molecules.

In accordance with Dalton's Law—Oxygen Partial Pressure:

$$(ppO_2) = \frac{21\%}{100\%} \times 760 \text{ mmHg} = 160 \text{ mmHg}$$

Inert Gas Partial Pressure:

$$(ppI) = \frac{79\%}{100\%} \text{(approx)} \times 760 \text{ mmHg} = 600 \text{ mmHg}$$

Carbon Dioxide Partial Pressure:

$$(ppCO_2) = \frac{0.03\%}{100\%} \times 760 \text{ mmHg} = 0.23 \text{ mmHg}$$

Now, let's see what happens to the breathing mixture at the operating depth of 130 feet. The pressure at depth is 3800 mmHg (760 mmHg × 5 atm abs). The air compressor on the ship is taking in air at the surface, normal pressure and normal mixture, and sending it down to the diver at a pressure sufficient to provide the necessary balance. The composition of the air is not changed, but the quantity being delivered to the diver is five times what he was breathing at the surface. More molecules of oxygen, nitrogen, carbon dioxide, are all compressed into the same volume at the higher pressure.

Employing Dalton's Law to determine the partial pressures at depth—

Oxygen Partial Pressure:

$$(ppO_2) = \frac{21\%}{100\%} \times 3800 \text{ mmHg} = 800 \text{ mmHg}$$

Inert Gas Partial Pressures:

$$(ppI) = \frac{79\%}{100\%} \text{(approx)} \times 3800 \text{ mmHg} = 3000 \text{ mmHg}$$

Carbon Dioxide Partial Pressure:

$$(ppCO_2) = \frac{0.03\%}{100\%} \times 3800 \text{ mmHg} = 1.14 \text{ mmHg}$$

SURFACE EQUIVALENT 2.4.4.2 From the previous calculations it is apparent that the diver is breathing more molecules of oxygen at depth than he would be if using 100% oxygen (760 mmHg) at the surface. He is also inspiring five times as many CO_2 molecules as he would breathing normal air on the surface. If the surface air were contaminated with 2% (0.02 atm) CO_2—a level which could be readily accommodated by a normal body at 1 ata—the partial pressure at depth would be a dangerously high 0.1 atm (0.02 atm x 5 atm). This partial pressure is commonly referred to as a surface equivalent (SE) of 10% CO_2:

$$SE = \frac{\text{pp at depth expressed in atms x 100\%}}{\text{1 atm}}$$

$$= \frac{0.1 \text{ atm}}{1.0 \text{ atm}} \times 100\% = 10\% \, CO_2$$

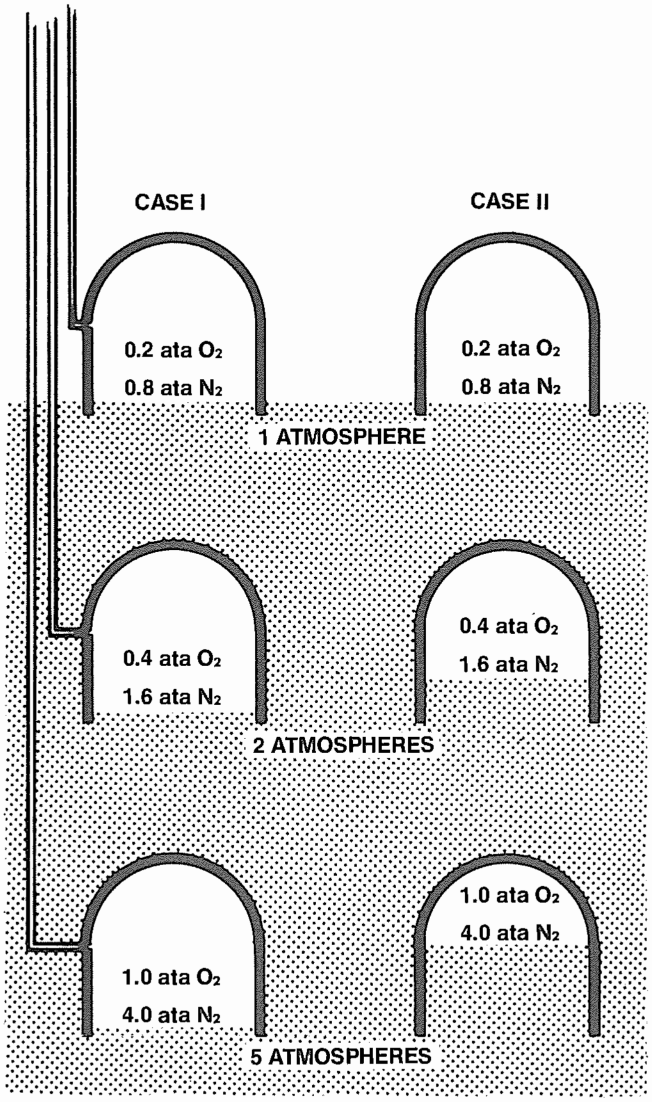


Figure 2-18 Partial Pressure:

In case I, similar to the situation in a diver's lungs, the partial pressures of the two gases (at constant volume) increase because of the addition of more gas molecules.

In case II, similar to an open-bottom diving bell, partial pressures of the two gases increase due to compression.

In both cases the sum of the partial pressures equals the hydrostatic pressure, and individual partial pressures increase in direct proportion to absolute pressure.

This term implies that the concentration and physiological effect of a gas at a given partial pressure at depth is the same as would be experienced at X% breathed on the surface (1 atmosphere). Although it is a commonly used term, "surface equivalent" is often misinterpreted, and it is preferable to use the more exact form of expressing partial pressure in units of pressure (atm, mmHg).

GAS DIFFUSION 2.4.4.3 Another physical effect of partial pressures and kinetic activity is that of gas **diffusion**. Gas diffusion is the process of intermingling or mixing of gas molecules. If two gases are placed together in a container, they will eventually mix completely even though one gas may be heavier. The mixing occurs as a result of constant molecular motion.

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

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

Humidity 2.4.5 Water vapor, like other gases, behaves in accordance with the gas laws. However, unlike other gases encountered in diving, water vapor condenses to its liquid state at temperatures normally encountered by man.

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

Humidity is related to the vapor pressure of water. If a quantity of water is placed in a jar and the jar is sealed, part of the water will evaporate into the gas space above the liquid. Water will continue to evaporate until the number of molecules of water vapor leaving the liquid surface is the same as the number returning. When this equilibrium condition is reached, the air space above the water is said to be **saturated** with water vapor. The partial pressure of water in the gas is directly related to the temperature of the liquid water. As the water and gas temperature is increased more molecules of water will evaporate into the gas until a new equilibrium condition and higher partial pressure are established. If the liquid and gas are cooled, water vapor in the gas will condense until a lower partial pressure condition exists. This phenomenon will occur regardless of the total pressure of the gas above the liquid. Consequently, the **maximum** partial pressure of water vapor that can exist in a gas is governed entirely by the temperature of the gas. The temperature at saturation is referred to as the **dewpoint**. A table of partial pressures of water vapor at saturation conditions is shown in Figure 2-19.

Two terms are commonly employed in discussions of humidity—absolute humidity and relative humidity. **Absolute humidity** is the mass of water vapor per unit volume of a gas mixture. The common unit of absolute humidity in the English system is grains per cubic foot (7,000 grains = one pound); in the Metric system it is grams per cubic meter. Figure 2-20 provides a table of absolute humidities of air under saturation conditions.

Relative humidity is the ratio, expressed in percent, of the amount of water actually present in a gas mixture to the amount of water vapor that could be present if the mixture were saturated at the same temperature. Relative humidity (RH) may be calculated in several ways. As an example, assume a gas is at 80°F and the dewpoint is 50°F. Calculate the relative humidity:

Method No. 1

(Using Partial Pressures of Water Vapor, Figure 2-19)

$$RH = \frac{9 \text{ mmHg (Sat @ 50°F)}}{26 \text{ mmHg (Sat @ 80°F)}} \times 100\% = 35\%$$

Method No. 2

(Using Absolute Humidity, Figure 2-20)

$$RH = \frac{4.076 \text{ Gr/Cu Ft (Sat @ 50°F)}}{10.934 \text{ Gr/Cu Ft (Sat @ 80°F)}} \times 100\%$$

$$= 35\%$$

Temperature °F	Temperature °C	Partial Pressure mmHg	Temperature °F	Temperature °C	Partial Pressure mmHg
30	−1	4	100	38	49
40	5	6	110	43	66
50	10	9	120	49	88
60	15	13	130	54	115
70	21	19	140	60	149
80	27	26	150	65	192
90	31	36	160	71	245

Figure 2-19 Partial Pressure of water vapor at saturation conditions in moist air

Temperature, °F	**0.0**	**1.0**	**2.0**	**3.0**	**4.0**
−10	0.285	0.270	0.257	0.243	0.231
−0	.481	.457	.434	.411	.389
+0	.481	.505	.529	.554	.582
10	.776	.816	.856	.898	.941
20	1.235	1.294	1.355	1.418	1.483
30	1.935	2.022	2.113	2.194	2.279
40	2.849	2.953	3.064	3.177	3.294
50	4.076	4.222	4.372	4.526	4.685
60	5.745	5.941	6.142	6.349	6.563
70	7.980	8.240	8.508	8.782	9.066
80	10.934	11.275	11.626	11.987	12.356
90	14.790	15.234	15.689	16.155	16.634
100	19.766	20.335	20.917	21.514	22.125
110	26.112	26.832	27.570	28.325	29.096
Temperature, °F	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**
−10	0.218	0.207	0.196	0.184	0.174
−0	.370	.350	.332	.316	.300
+0	.610	.639	.671	.704	.739
10	.985	1.032	1.079	1.128	1.181
20	1.551	1.623	1.697	1.773	1.853
30	2.366	2.457	2.550	2.646	2.746
40	3.414	3.539	3.667	3.800	3.936
50	4.849	5.018	5.191	5.370	5.555
60	6.782	7.009	7.241	7.480	7.726
70	9.356	9.655	9.962	10.277	10.601
80	12.796	13.127	13.526	13.937	14.359
90	17.124	17.626	18.142	18.671	19.212
100	22.750	23.392	24.048	24.720	25.408
110	29.887	–	–	–	–

Figure 2-20 Absolute Humidity—weight in grains of the aqueous vapor contained in a cubic foot of saturated air.

Two additional terms, wet-bulb and dry-bulb temperatures, are used in humidity studies. **Dry-bulb temperature** is the actual temperature of the gaseous atmosphere. **Wet-bulb temperature** is the temperature to which the atmosphere must be cooled to become saturated (dewpoint). The wet bulb temperature is always lower than the dry bulb, except at 100% RH when they are both the same.

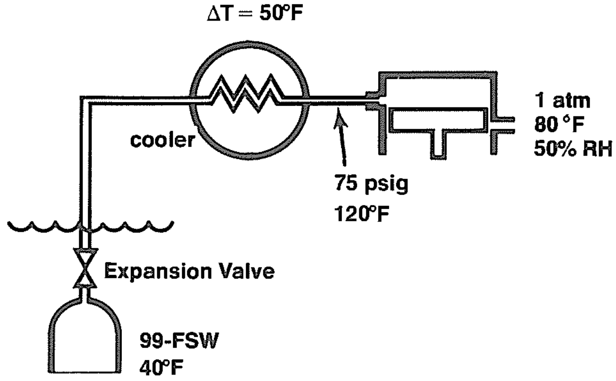
When a moist gas is compressed into a constant volume receiver, water is continually added. Under these conditions the absolute and relative humidities and the partial pressure of water vapor are increased. When the partial pressure of the water vapor reaches the level corresponding to saturation at the temperature of the gas, further compression results in condensation of water within the tank. In contrast, when a compressed gas is expanded, humidity and the partial pressure of water vapor decreases. As a consequence, air supplied to a diver from a high pressure cylinder is very dry, whereas air supplied directly from a compressor is usually saturated (100% RH) unless water removal equipment is used.

Without adding water vapor to a gaseous atmosphere, raising its temperature at constant pressure will decrease the relative humidity. Since the dry bulb temperature is increased, the atmosphere could contain more water vapor. The partial pressure of water vapor, however, will remain unchanged. Conversely, lowering the temperature would increase the humidity until the partial pressure of water vapor in the atmosphere corresponded to the saturation value. Further cooling would result in condensation of water and an associated decrease in the partial pressure of water vapor in the atmosphere.

In air diving removal of excess water and reduction in the dewpoint are usually accomplished by a combination of sea water coolers on the compressor and expansion of the air. The following example will illustrate the calculation for this type of procedure:

Compressor inlet air—80°F, 50% R.H., 1 ata
Compressor outlet air—120°F, 75 psig
Temperature drop across cooler—50°F
Diver depth—99 f.s.w. (4.0 ata)

Determine the amount of water removed from the air in the cooler and the relative humidity and dewpoint temperature of the air in the diver's helmet.



First, compute the partial pressure of the water vapor (PP_{H_2O}) in the air leaving the compressor. The PP_{H_2O} of saturated air at 80°F, from Figure 2-19, is 26 mmHg. At 50% relative humidity, the PP_{H_2O} of the air entering the compressor is—

$$PP_{H_2O}\text{ in} = \frac{50\%}{100\%} \times 26\text{ mmHg}$$

$$PP_{H_2O}\text{ in} = 13\text{ mmHg}$$

After the air is compressed to 75 psig, the PP_{H_2O} becomes—

$$PP_{H_2O} = 13\text{ mmHg} \times \frac{75 + 14.7}{14.7}$$

$$= 13\text{ mmHg} \times 6.1\text{ ata}$$

$$= 79\text{ mmHg}$$

From Figure 2-19, the saturation temperature corresponding to 79 mmHg is 115°F. Since the discharge temperature of the air leaving the compressor is greater than 115°F, no moisture will have precipitated out inside the compressor. (If the discharge temperature were less than 115°F, that temperature would be used to determine the absolute humidity of the air leaving the compressor.) From Figure 2-20, the absolute humidity of air saturated at 115°F is 29.89 grains/cubic foot (gr./cu. ft.).

As the discharge air passes through the cooler, its temperature goes from 120°F to 70°F. From Figure 2-20, the absolute humidity at 70°F is 7.98 gr./cu. ft. The quantity of water removed in the cooler is—

29.89 gr./cu. ft. − 7.98 gr./cu. ft. = 21.91 gr./cu. ft.

The air being delivered to the diver is at 75 psig and 70°F. From Figure 2-19, the PP_{H_2O} of this air is 19 mmHg. After its expansion across the air control valve, the relative humidity of the air becomes—

$$RH = \frac{PP_{H_2O}\text{ in helmet}}{PP_{H_2O}\text{ saturated}} \times 100\%$$

$$PP_{H_2O}\text{ in helmet} = \frac{4.0\text{ ata}}{6.1\text{ ata}} \times 19\text{ mmHg}$$

$$= 12.5\text{ mmHg}$$

$$RH = \frac{12.5\text{ mmHg}}{19\text{ mmHg}} \times 100\% = 66\%$$

The corresponding dewpoint temperature of the air in the helmet, from Figure 2-19, is approximately 58°F.

Gases In Liquids 2.4.6 Whenever a gas is in contact with a liquid, a portion of the gas molecules will enter into solution with the liquid. They are said to be **dissolved** in the liquid. This factor of solubility is of vital importance since significant amounts of gases are dissolved in body tissues at the gas pressures encountered in diving.

Some gases are more soluble than others, and some liquids are better solvents than other liquids. For example, nitrogen is five times more soluble (on a weight for weight basis) in fat than it is in water.

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

HENRY'S LAW 2.4.6.1 Henry's Law states that **the amount of gas that will dissolve in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas.** If one unit of gas is dissolved at one atmosphere, then two units will be dissolved at two atmospheres, three units at three atmospheres, etc.

When a gas-free liquid is first exposed to the gas, quantities of gas molecules will rush to enter into solution, pushed along by the partial pressure of that gas. As the molecules enter the liquid, they add to a state of **gas tension**, which is a way of identifying the partial pressure of that gas in the liquid. The difference between the gas tension and the partial pressure of the gas outside the liquid is called the **pressure gradient**, which gives an indication of the rate at which the gas will tend to enter or leave the solution. When the gradient is high—with low tension and high partial pressure–the rate of absorption into the liquid is high. As the number of molecules of gas in the liquid increases, the tension increases until it reaches a value equal to the partial pressure and at that point, the liquid is **saturated** with the gas and the pressure gradient is zero. Unless there is some change in temperature or pressure, the only molecules of the gas to enter or leave the liquid are those which may, in random fashion, change places without altering the balance.

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

The gases in a diver's breathing mixture will be dissolved into his body in proportion to the partial pressure of each gas in the mixture. Because of the varied solubility of different gases, the quantity of a particular gas which becomes dissolved will also be governed by the length of time the diver is breathing the gas at the increased pressure. If the diver breathes the gas long enough his body will become saturated, but saturation of the body occurs slowly. Depending on the gas, it takes anywhere from 8 to 24 hours.

Whatever the quantity of gas which has been dissolved in a diver's body, at whatever depth and pressure, it will remain in solution as long as the pressure is maintained. However, as the diver starts to ascend toward the surface, more and more of the dissolved gas will come out of solution. If his rate of ascent is controlled—as through use of the decompression tables—the dissolved gas will be carried to the lungs and exhaled before it accumulates sufficiently to form bubbles in the tissues. If, on the other hand, he rises suddenly and the pressure is reduced at a rate higher than the body can accommodate, bubbles may form and become trapped in the small blood vessels causing pain in the area of the joints. The associated pain and discomfort of decompression sickness is treated by repressurization to redissolve the bubbles followed by slow decompression using special tables.

Summary of the Laws Relating To Gases 2.4.7

$PV = C$	$\frac{PV}{T} = K$	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
Boyle's Law	**Charles' Law**	**General Gas Law**

$$P_{TOTAL} = PP_A + PP_B + PP_C \cdots$$
$$PP_A = P_{TOTAL} \times \%\ Vol_A$$

Dalton's Law

Boyle's Law describes the relationship of pressure and volume: as absolute pressure increases, volume decreases proportionally; as absolute pressure decreases, volume increases.

Charles' Law describes the relationship of temperature to pressure and volume: if volume is constant, the pressure will change directly as the absolute temperature changes. If the pressure is constant, the volume will change directly as the absolute temperature.

The General Gas Law is a convenient combination of Boyle's and Charles' Laws.

Dalton's Law, also called the "Law of Partial Pressures," points out that each gas in a mixture of gases will exert a pressure, which is a part of the total pressure of the mixture, and is equal to whatever pressure that gas would exert if it was all by itself in the volume being considered.

Henry's Law states that the amount of gas that will dissolve in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas.

ENERGY IN DIVING 2.5

As was previously discussed in Section 2.1.2, the total subject of energy is vast, complex and beyond the scope of this manual. Four of the six types of energy—mechanical, heat, electrical, and chemical—are commonly encountered in diving operations in a wide variety of forms. Only those forms, however, which have unusual effects underwater will be discussed in this section—light, sound and heat.

Light 2.5.1 The human eye needs light in order to see, because what it sees is actually an image created by the reflection of light from various surfaces, objects or particles in the air. Under water, light is affected by some factors not usually encountered on the surface, and these directly influence what a diver will see. Among these factors are diffusion, which scatters the light, turbidity, which blocks the light, absorption, which alters the color and intensity of the light, and refraction, which "bends" the light.

The light that does penetrate the water decreases in intensity with depth, as the light rays are scattered and absorbed. In clear water, enough light remains for vision to about 300 feet (100 meters) but if the water is very turbid—filled with impurities such as silt, algae and chemical pollution—the light is cut-off much sooner. If the level of turbidity is high, vision may be blocked by the particles even though light may be present; if the turbidity is severe, as in most harbors and rivers in the urban areas, the diver will be "blind" the minute he goes below the surface.

Just as the level of light is changed, so is the color quality of the light. The color of the water itself is influenced by many factors—including the color of the sky (whether blue or dull gray), the quantity and nature of suspended particles such as sand or algae, and the distance to the bottom. Colors underwater are modified with depth, because wavelengths of the visible spectrum are progressively absorbed by the water and effectively filtered out. This happens at very shallow depths at the red end of the light spectrum. As depth is increased yellow light disappears and at this point most objects take on a blue color and red objects appear black.

Light rays in water are diffused—scattered and deflected in all directions. This diffusion, contributes to the reduction in total illumination, but at the same time tends to aid vision by spreading the light evenly through the water at any given depth. Shadows are softened and often eliminated.

The condition of refraction makes a diver think his eyes are playing tricks on him. Underwater, he may try to pick up a rock which seems to be well within reach, only to find that he can't touch it. Or, standing in shallow water, he may try to poke at a shell with a stick, and not only does he miss, but the stick seems to suddenly bend the moment it enters the water.

This sort of visual deception results from the fact that light rays travel at different speeds in air and water—faster in air on a ratio of about four to three. When a light ray passes from one medium to the other at an angle, it will actually change direction as it either slows down or speeds up. This causes an apparent displacement of objects. The effect is most pronounced for a diver wearing a face mask or a helmet with a glass faceplate. The rays of light, reflected from an object, must first pass through the water, then the glass and then the air inside the mask or helmet before reaching the lens of the eye. At each interface, as it enters a more or less dense medium, it will be refracted.

Because of the refraction, objects underwater appear to be larger, and therefore closer, on a ratio of four (apparent) to three (actual). That rock that seemed just within reach is actually about a foot further away; a fish 20 feet (6.5 meters) from the diver will seem to be about 15 feet (5 meters) away.

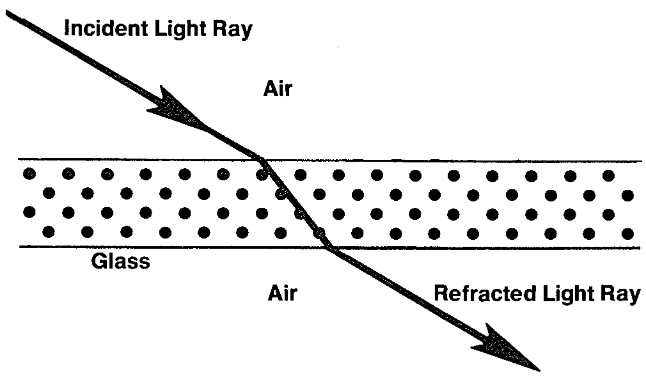


Figure 2-21 Refracted Light—as light ray passes through mediums of different density, they are refracted (bent) and displaced.

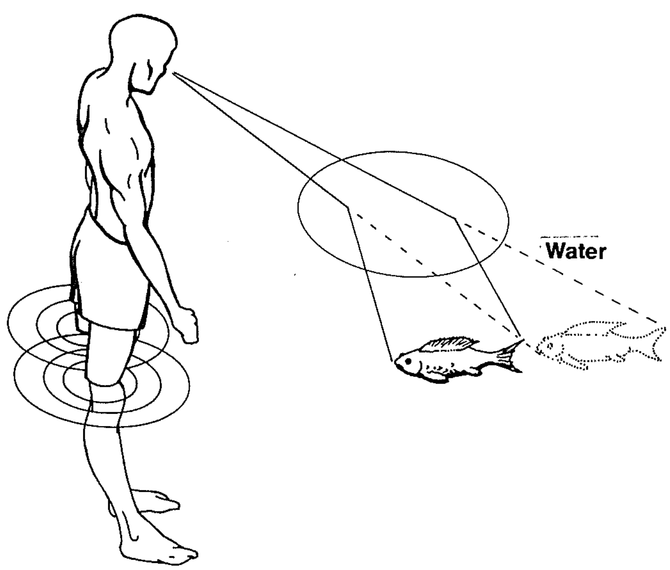


Figure 2-22 Light rays are refracted as they enter water. The fish above is actually in the location shown by the dotted outline, but the man observing it sees it forward of its actual location.

Sound 2.5.2 The differences in sound underwater are in many ways similar to the differences in light. Sound, like light, is made up of waves which seem to behave in an alien fashion in the water; however, with sound, the waves are waves of "pressure" rather than of radiation.

Sound is produced by the vibration of an object, which sets up a pattern of waves of moving molecules in the air, water or other medium. These waves, in turn, cause a sympathetic vibration in a detector such as an eardrum or the diaphragm of a microphone.

Sound travels best in a dense medium, since the more closely packed molecules more efficiently transmit the waves, and sound will not travel at all in a vacuum because there are no molecules.

Water, which is fairly dense, is an excellent sound conductor and will transmit at a rate of about 3,240 mph (1,500 m/sec). This is approximately four times the speed of sound in air. The efficiency at which sound moves in water has long been put to practical application by mariners. In the early years of this century, underwater bells were placed at 135 coastal lighthouse stations, world-wide, to give audible warning of proximate danger. The sound of the bells traveled about 15 miles (24km) underwater, in any weather, and was picked up by a ship using a microphone mounted inside the hull. During the First World War, "listening devices" helped in locating and tracking submarines and, later, the development of active sonar—which sends out a sound and picks up any echo of that sound from an underwater object—improved antisubmarine warfare capabilities.

In contrast, however, since sound travels so fast underwater, human ears cannot detect the difference in time of arrival of a sound between each ear. Consequently, a diver loses the ability to locate the direction of a sound source. This disadvantage can have serious consequences for diver or swimmer in locating objects and sources of danger, e.g., powerboats.

Variations in temperature of various layers of water called thermoclines can cause refraction, or bending, of the sonar pulse. The bending of the sound pulses can produce false echoes which cause problems for sonar operators attempting to obtain bearings on underwater targets, and can also seriously interfere with communications between surface ships and submarines using the underwater telephone (UQC).

Talking underwater, as one would talk on the surface, is impossible. Man's vocal chords are designed to operate in an environment of air, and sound cannot cross from air to water, or from water to air, to any major extent. Two divers wearing deep-sea gear can put their helmets together and carry on a conversation, since the metal in the helmets easily conducts the sound of their voices. However, if they are separated by only a few inches of water, vocal communication is impossible.

Since water is a better conductor of sound than air, noises of a given intensity will be heard more clearly and rapidly than the equivalent noise at the same distance in air. This characteristic must always be considered in conducting underwater operations which may produce damaging noise levels to divers that might readily be absorbed if performed on the surface.

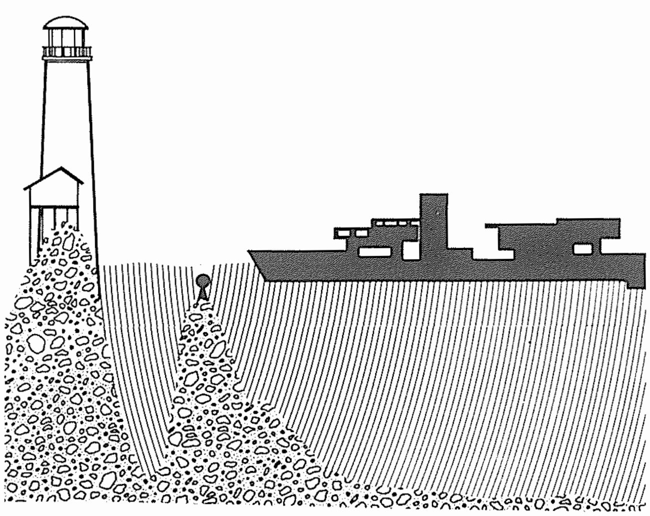


Figure 2-23 Water, being a much better sound conductor than air, permits ships to hear submerged shore warnings from as far as 15 miles away.

Heat 2.5.3 Heat, or the absence of it, is crucial to man's environmental balance. The human body functions only within a very narrow range of internal temperature, and contains delicate mechanisms to control that temperature which will be examined in detail in Chapter Three, "Diving Physiology." The external factors which influence body temperature are included in this present chapter on "Underwater Physics."

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 it because different substances do not necessarily contain the same heat energy even though their temperatures are the same. Temperature is measured in degrees, usually Fahrenheit or Celsius as discussed in Section 2.2. Heat is measured in British Thermal Units (Btu's), calories, or kilogram-calories. One Btu is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. A calorie is the amount of heat required to raise the temperature of a gram of water one degree Celsius, and a kilogram-calorie is the corresponding amount for a kilogram (1000 grams) of water.

Specific heat is the ratio of the amount of heat transferred to raise a unit mass of a substance 1 degree to that required to raise a unit mass of water 1 degree. Specific heat, like specific gravity, is a ratio that uses water as the base with a value of 1.0. The specific heat of air is 0.24, which means that 0.24 calories will raise the temperature of a gram of air by 1°C. If one converts air from a weight to a volume basis and compares it with water, it will be found that a volume of water will absorb 3,600 times as much heat as a volume of air for the same rise in temperature.

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

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

Convection is the transmission of heat by the movement of heated fluids. This is the principle behind the operation of most home heating systems, which set up a flow of air currents based on the natural tendency of

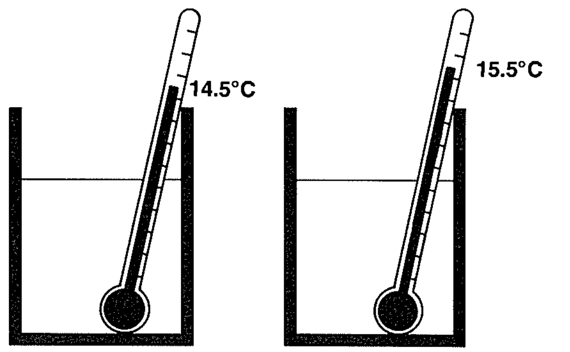


Figure 2-24 A calorie is the amount of heat required to raise the temperature of 1 cc of water 1°C

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 in the tank. The warmed water passing along the walls of the tank, or reaching the surface, will lose heat to the cooler surroundings. Once cooled, the water will sink only to be warmed again as part of a continuing cycle.

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

Of the three, conduction is of most significance to divers. The rate at which heat will be transferred by conduction depends on two basic factors—the difference in temperature between the warmer and cooler material, and the conductivity of the materials. Some substances are excellent conductors of heat—for example, iron, helium, and water. Some, like air, are very poor conductors. A poor conductor, if placed between a source of heat and another substance, will insulate the substance and appreciably slow down the transfer of heat. Most of the materials used for insulation of the human body—such as wool, or foam plastics—are effective because they contain thousands of pockets of trapped air, each too small to be subject to convective currents but each blocking conductive transfer of heat.

A diver's experience with temperatures in the home does not give him a basis with which to evaluate the heat problems he will encounter underwater. The water temperature below which a diver will start to become chilled is a seemingly comfortable 70°F (21°C). Below that temperature, a diver wearing only a swimming suit will lose heat to the water faster than his body can replace it, and unless he is provided with some protection or insulation, he may soon experience difficulties. A diver who is chilled cannot work efficiently, nor think clearly, and is more subject to decompression sickness.

Several factors contribute to the problem of maintaining a diver's body temperature including—suit compression, increased gas density, thermal conductivity of breathing gases, and respiratory heat loss. The cellular neoprene wet suit loses a major portion of its insulating quality as depth increases and the material is compressed. A normal wet suit loses 60% of its insulating quality at 33 feet when it is used at 165 feet. As a consequence it is often necessary to employ a thicker suit, a dry suit, or a hot water suit for extended exposures at greater depths.

The heat transmission characteristics of a gas are directly proportional to its density. Therefore, heat loss through gas insulating barriers and respiratory heat lost to the surroundings increases with depth. This situation is further aggravated when high thermal conductivity gases, such as helium-oxygen (7 × air), are used for breathing. The respiratory heat loss alone increases from 10% of the body's heat generating capacity at 1 atm, to 28% at 7 atm, to 50% at 21 atm when breathing heliox. Under these circumstances insulating materials are insufficient to maintain body temperature, and supplementary heat (usually hot water) must be supplied to the body surface and respiratory gas.

SUMMARY

These principles of physics provide the keystone in understanding the reasons for employing various diving techniques and procedures, and the operation of associated equipment. They also assume particular significance in studying the effects of the underwater environment upon the human body. ■

CHAPTER THREE

UNDERWATER PHYSIOLOGY

Physiology is the study of the functions and vital processes of living organisms. Anatomy is the study of the organization and structure of the body—the housing in which the processes of physiology are carried on. It is important for the diver to have a basic understanding of his body and its vital processes so that he will respect the increased demands that the underwater environment imposes upon him. This chapter presents a general discussion of the physiology and anatomy necessary for this basic understanding. It then expands these subjects to provide a comprehensive understanding of how normal physiology is affected by diving.

THE STRUCTURE OF THE BODY 3.1

The human body is a combination of interdependent systems, each with certain specialized functions. Those major systems which are of particular importance to a diver are—

- SKELETAL
- MUSCULAR
- NERVOUS
- CIRCULATORY
- RESPIRATORY
- DIGESTIVE/EXCRETORY

The skeletal system provides the basic structure around which the body is formed: it gives strength to the body and protection to the vital organs. Muscles make the body move—every movement from the blinking of an eye to pulling the whole body through a long distance race. Additionally, they offer protection to the vital organs in the body. Some muscles are controlled by conscious effort, while others perform their functions automatically whether the person is waking or sleeping, whether he is aware of their activity or not.

The nervous system includes the brain, the spinal cord and a complex network of nerves. It coordinates all body functions and activities. The basic unit of the nervous system is the neuron, a particular type of cell which has the ability to transmit electrochemical signals, which relay data to and from the brain, at speeds as great as 350 feet per second There are about 10 billion neurons in the body, the smallest of which are microscopic and the largest of

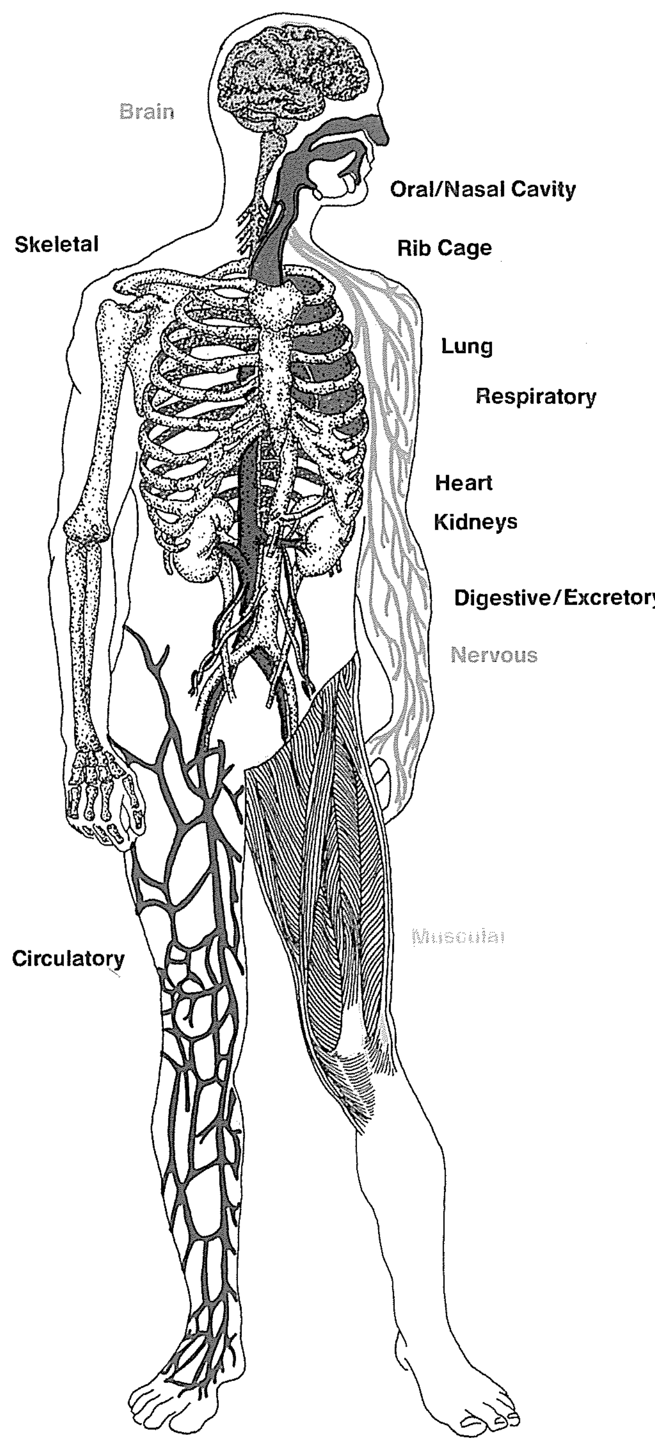


Figure 3-1 Man's physiological systems—included in this partial cutaway view are elements of the various body systems.

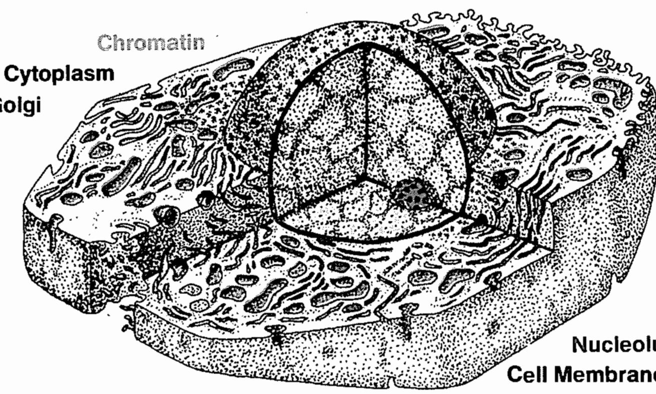


Figure 3-2 Cutaway of a typical cell—Although cells vary greatly in shape all have three basic components: nucleus, cytoplasm and cell membrane.

which have fibers which reach all the way from the spinal cord to the big toe.

All parts of the body—all of the bones, muscles, nerves, and vital organs—are made up of cells and tissue fluids. There are many kinds of cells, but most have a common characteristic: the ability to utilize the energy derived from food in some useful way.

The process of converting food into energy can best be described as a slow, flameless burning (oxidation) of food materials when combined with oxygen in the cell. Carbon dioxide is produced as a waste product. Not all of the food provided to the cells, however, is immediately converted into energy. Some of it is used in building new tissue, and some is stored as a source of future energy. The general term which is applied to the processes by which the cells work with food materials is metabolism.

Metabolic processes continue in the cells every second of life, and for this a constant supply of food, oxygen and various chemicals (enzymes) is required. The digestive system converts food to a form that can be transported to, and utilized by, the cells. Through a combination of mechanical, chemical and bacteriological actions, the digestive system reduces food into soluble basic materials such as amino acids, fatty acids, sugars and water. These materials diffuse into the blood and are carried by the circulatory system to all of the cells in the body.

The oxygen required for the metabolic process is also carried in the blood. Oxygen is brought into the body by the respiratory system, consisting of the lungs and the passages of the nose and throat through which air reaches the lungs. As the lungs fill with air, the oxygen diffuses into the blood. When blood passes cells which need the oxygen, some of it will diffuse out of the blood, through the tissue fluids surrounding the cells and then through the membranous wall of the cell itself.

Metabolism produces certain waste materials which must be removed from the cells. Solid and liquid wastes are dissolved in the blood as it flows past the cells, and are carried to the kidneys where they are filtered out. These wastes are then passed to the bladder for temporary storage as urine. Carbon dioxide and other gaseous wastes are carried by the blood to the lungs, where they are passed out of the body as part of the exhaled breath.

The metabolism is influenced by the rate at which the body needs energy. When a person sleeps, for instance, his metabolic rate is low and respiration and circulation proceed at a matching low level. When body activity is increased, the respiratory and circulatory level must also increase to supply more food and more oxygen to the cells, and to remove the greater quantity of waste materials.

THE INTERDEPENDENCE OF THE BODY SYSTEMS 3.2

An interruption or disruption of one of the systems will have some effect upon the rest of the body, but in most cases the effect can be tolerated while the problem is being corrected. A broken bone or cut muscle, for instance, may impair locomotion, but the body will usually continue to function in an acceptable manner

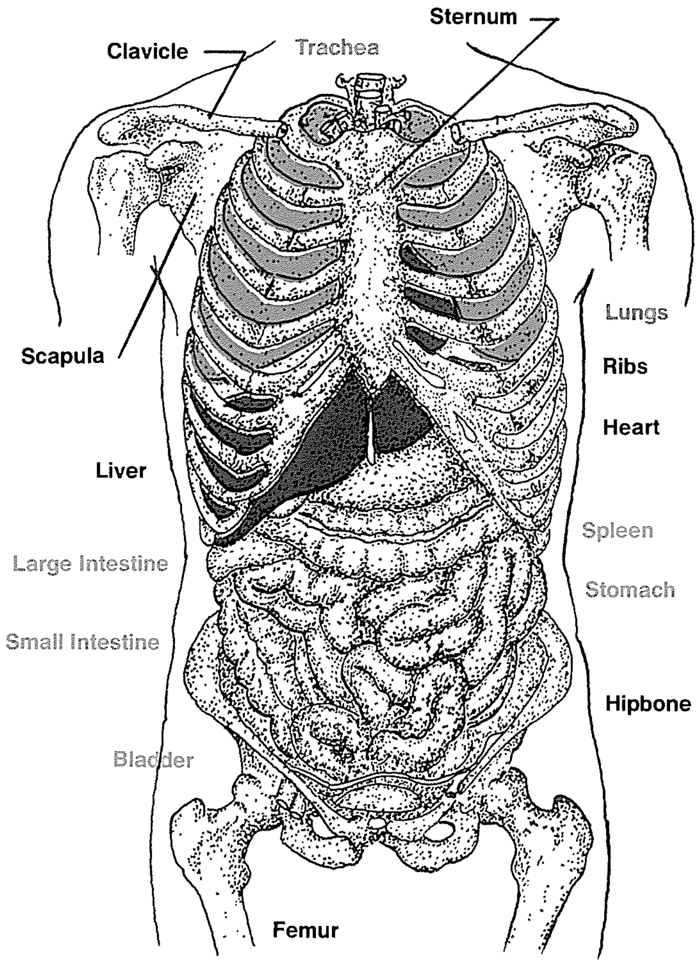


Figure 3-3 Thoracic and abdominal viscera shown in relation to the skeleton.

while the basic metabolic processes work to repair the damage. An injury to the nervous system might be permanent, causing paralysis or blindness, but the unaffected parts of the body may continue to function normally. The average person can live for several weeks without taking in any new food supplies, provided that the body is supplied with water to carry off chemical wastes of metabolism. The body cells will extract energy as necessary from stored food materials already in the body.

However, the body is not very successful in handling interruptions of the respiratory and circulatory systems. A person can function for only a few minutes without breathing before the cells, deprived of a fresh supply of oxygen, will begin to die. Those most immediately affected will be the cells of the brain, which normally use 20% of the entire blood's oxygen supply. Brain cells will begin to die in about four minutes. If performed promptly, mouth-to-mouth resuscitation or the administration of 100% oxygen with a resuscitator may restore respiration before cellular damage becomes too widespread.

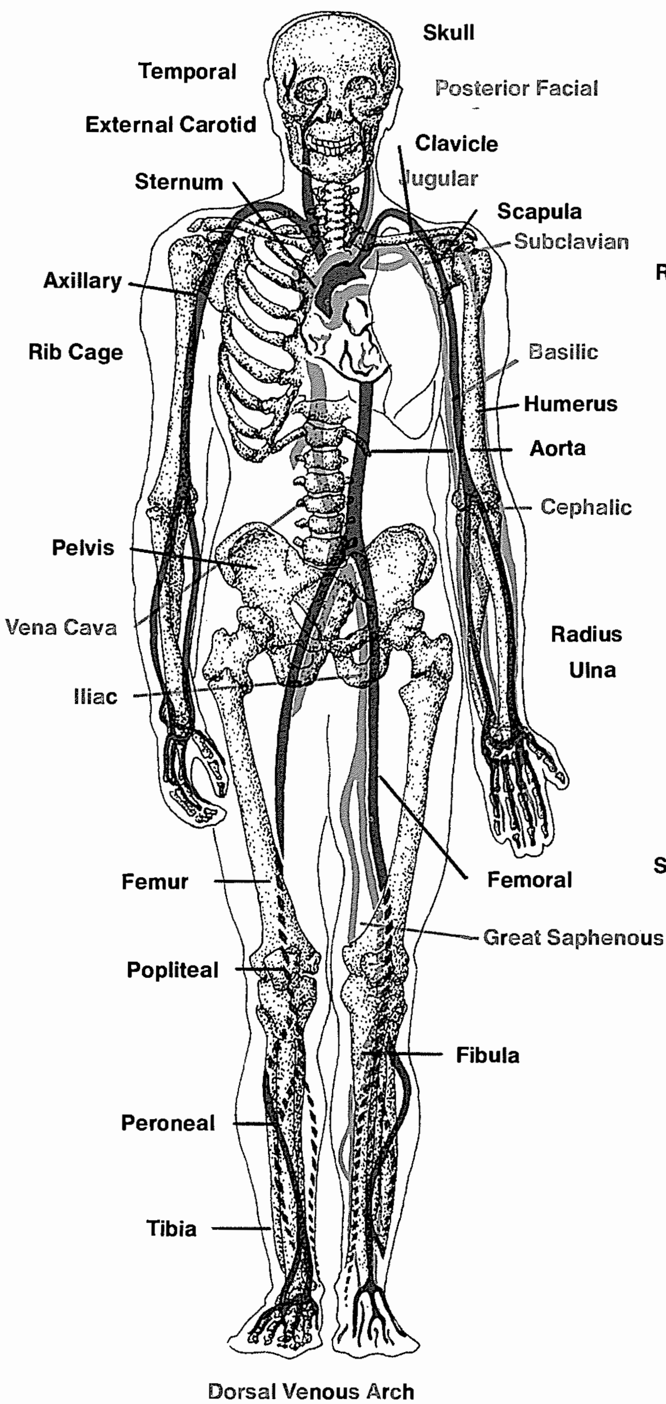
Major disruption of the circulatory system can have an even more drastic and immediate effect on the body. If the heart should stop beating, thus halting the circulation of the blood, the cells in the brain will suffer damage almost immediately. With this occurrence, all the systems of the body are threatened. The pumping action of the heart can sometimes be restored by heart massage, or electrical and chemical stimuli, which to be effective, must be administered immediately (See Chapter Eight, DIVING EMERGENCIES).

The respiratory and circulatory systems are so vital to the body that anything which interferes with them can result in serious problems. By its very nature, the underwater environment poses continuing hazards to respiration and circulation. A diver must have a particularly thorough understanding of both the anatomy and physiology of these two systems.

THE CIRCULATORY SYSTEM 3.3

The blood moves through a network of blood vessels, the largest of which is about one inch in diameter with thick, muscular walls. The smallest are so slender that 10 of them together would equal the thickness of a human hair.

The arteries are the largest and strongest of the blood vessels, and always carry blood being pumped away from the heart. Starting at the heart with the aorta (the largest artery), the arterial system divides and re-divides into smaller arteries and then into the arterioles ("little arteries"). The arterioles branch out into the capillaries, the smallest and most numerous of the blood vessels. The capillaries are distributed throughout the body so that very few cells are more than a fraction of a millimeter away from at least one of them.



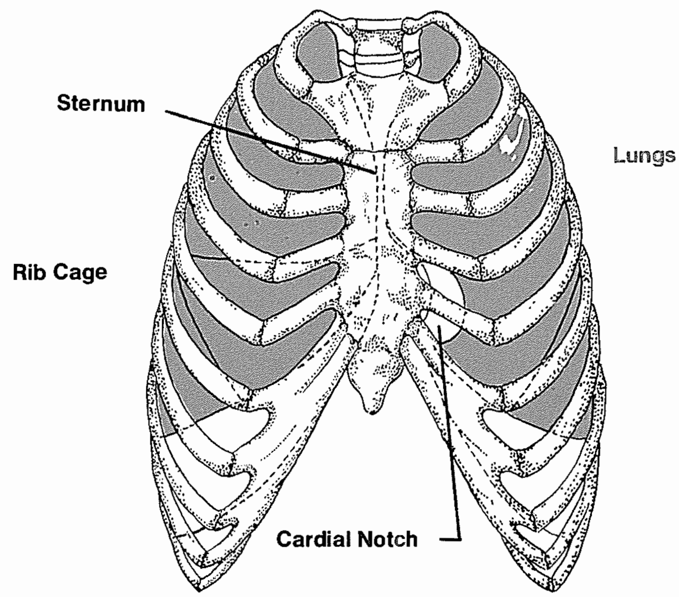


Figure 3-5 Rib cage and Lungs (frontal view).

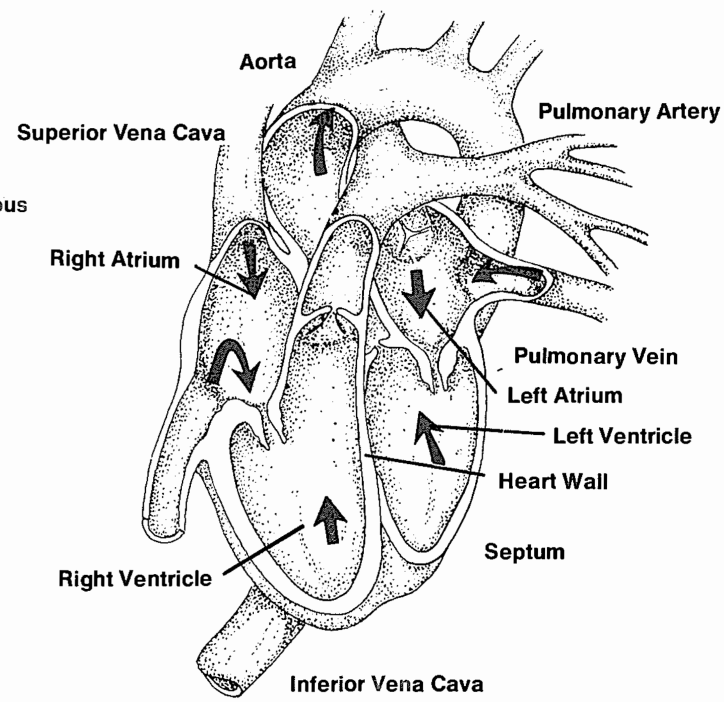


Figure 3-4 Arterial-Venous system projected on frontal view of human skeleton.

Figure 3-6 The heart—A cutaway view illustrating the major components and blood flow.

The capillaries mark the end of the outward flow of blood, and also mark the beginning of the return flow toward the heart. This occurs through a system of veins, starting with the smallest (the venules) which merge into increasingly larger veins. The venous system always leads toward the heart; at the end of this network, the blood is channeled into the heart through the largest vein, the vena cava.

The Heart 3.3.1 The heart is actually two pumps, side by side and completely separated from each other by a dividing wall. The pump on the right side of the heart takes the blood from the vena cava and forces it through the lungs (the pulmonary circuit of the blood) and then into the left side of the heart. From there, the blood is pumped through the rest of the body (via the systemic circuit) and eventually back into the right side of the heart. The average heart is about the size of a clenched fist. It sits in the chest, just slightly to the left of center, where it is nestled in the lungs and protected by the breastbone (the sternum) and ribs.

Each half of the heart—each pump—has two chambers. The upper chamber, or atrium, receives the incoming blood and passes it down to the lower, more muscular chamber, the ventricle. Both ventricles—left and right—contract at the same time to force the blood out through the circulatory system. Special valves in the heart prevent the blood from flowing in the wrong direction.

The Blood 3.3.2 Blood has four main components

—50% fluid plasma

—45% red cells (erythrocytes)

— 5% white cells (leukocytes)
and platelets (thrombocytes)

Plasma is a yellowish solution, 92% water, that carries the red and white cells, as well as a number of other substances. These include basic nutrients, various chemicals, special proteins and hormones, and some quantity of dissolved gas. The 25-trillion red cells in the blood carry the bulk of the oxygen to the body cells, where they exchange it for carbon dioxide. Some oxygen is dissolved in the plasma, but the quantity is so small that it cannot support the needs of the body. The oxygen transport is made possible because of a substance contained in the red cells which has a particular affinity for oxygen. This is hemoglobin, an iron-rich compound which forms a loose chemical bond with oxygen in the lungs, and releases the oxygen to the cells of the body as required. When the hemoglobin is enriched with oxygen, it is bright red in color. As the oxygen level is reduced, the color changes to a dark, dull and almost bluish hue.

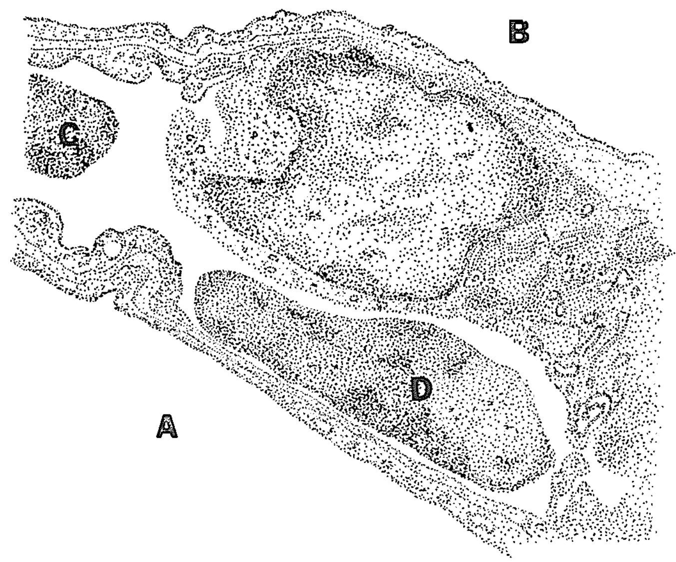


Figure 3-7 Gas is diffused across air spaces A and B to and from the red blood cells C and D, which are moving through a pulmonary capillary.

Carbon dioxide is carried by the blood in several different ways. About one half of it is dissolved in the plasma, and the remainder enters into a chemical combination with the hemoglobin. Upon reaching the lungs, the hemoglobin instantly gives up its share of carbon dioxide in exchange for oxygen.

There are several types of white cells, but each type works to keep the body free of infection by attacking and consuming invading bacteria. The white cells are outnumbered by the red cells on the order of 700 to 1. However, when faced with an infection the body produces additional white cells so rapidly that the number in the system may double within a few hours. The third type of cell in the blood is the platelet, which is involved in the clotting process.

Circulatory Rate 3.3.3 The average body contains a fairly constant quantity of blood, about 40cc/pound of lean body weight. However, the amount of blood pumped through the heart in any given period will vary with the needs of the body. In an average day, the heart may actually pump more than 7,200 liters of blood.

Cardiac output is a measure of the amount of blood pumped by the heart in a stated period of time, usually expressed in "liters per minute." With the body at rest, the heart may beat 60 to 70 times a minute and the cardiac output might be 5 liters per minute. With the body engaged in hard work, this rate may reach 150 beats per minute with a cardiac output of 35 liters per minute. The heart not only beats faster, but it also enlarges to handle a greater volume with each beat.

The heartbeat rate is controlled by a small section of nervelike tissue located in the right atrium—the sinus node. This is the "pacemaker" of the heart, regularly sending a small electrical impulse through the heart muscle, causing it to contract.

Blood Pressure 3.3.4 Every beat of the heart sends a surge of pressure through the circulatory system—a surge which is great at the heart and gradually diminished in force as it spreads through the body. This surge can be seen or felt, as the pulse, in those arteries which are near the surface of the skin.

The pulses can be counted, to determine the rate of heartbeat and pulse pressure can be measured to determine the force of the heartbeat. Blood pressure fluctuates with each beat of the heart. It is at a low level when the heart is relaxed, and at a higher level when the heart has contracted, forcing a volume of blood into the system. A pressure reading at the low level is called the diastolic pressure, and at the high level, the systolic pressure.

This pressure is measured in millimeters of mercury and is expressed as "systolic over diastolic." A normal reading for a young man at rest might be about 120/80—a systolic pressure of 120mm Hg and a diastolic reading of 80mm Hg. Both pressures would increase during periods of exertion or excitement, but should soon return to normal with the body relaxed and at rest.

Control of Blood Flow 3.3.5 If a man is running, the muscles in his legs will be working harder than those in other parts of his body and will need a greater supply of blood. Certain mechanisms in the circulatory system help to ensure that these working muscles will receive the necessary supply. Capillaries and some arteries have the ability to dilate, increasing their diameter and thereby effectively direct a greater proportion of the blood supply to the exercising muscles. Mechanisms which come into play in some forms of shock lead to a decrease in blood flow through certain organs, thereby protecting the brain and heart at the expense of the less-important extremities.

Cardiac rate and the diameter of some blood vessels in the muscles are increased by a substance secreted in the adrenal glands—adrenaline. The pounding of the heart which follows a sudden fright, for example, is caused by a boost in the quantity of adrenaline in the system, giving the body the extra surge of blood it would need for action.

Fainting and Shock 3.3.6 On occasion, physical or psychological stress may bring about a temporary lowering of the blood pressure to a point where the brain may not be receiving enough blood. When this happens, a person will feel light-headed, may suddenly feel very weak and may even faint—that is, loose consciousness and fall. Usually, he will revive quickly when the flow of blood to the brain more nearly approaches normal. Falling down is in itself a corrective action, since, by lowering the head in relation to the heart, it permits more blood to reach the brain in spite of the reduced pressure.

Shock is a serious condition brought about by hemorrhage, severe burns, or other situations which radically lower the blood pressure or allow the actual loss of blood or blood fluids to a point where pressure and flow cannot be maintained in the circulatory system. Not only the brain, but all of the tissues of the body might be affected. A particular danger in an instance of shock is that there may have been no visible loss of blood or fluids (as when hemorrhaging is internal) and the victim might seem merely to have fainted.

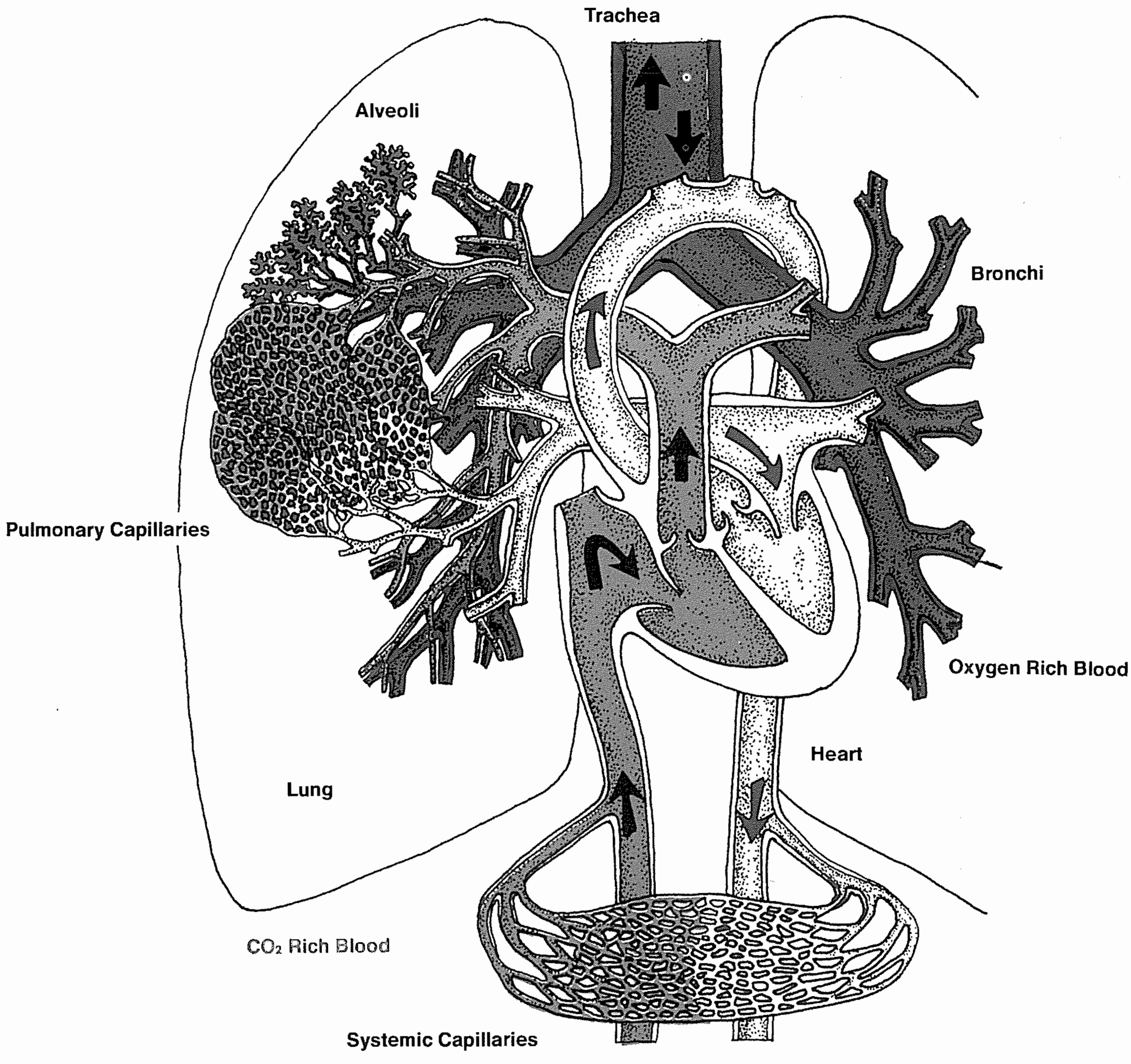


Figure 3-8 The lungs' gas-exchange system is essentially three pumps. A gas pump, the thorax, moves air through the trachea and bronchi to the lungs' air sacs. These sacs, the alveoli, are shown with and without their covering of pulmonary capillaries.

The heart's right ventricle, a fluid pump, moves blood which is low in oxygen and high in carbon dioxide, into the pulmonary capillaries. Oxygen, from the air is diffused into the blood while carbon dioxide is diffused from the blood into the air in the lungs. The oxygenated blood moves to the left ventricle, another fluid pump, which sends the blood to the systemic capillaries which deliver oxygen to and collect carbon dioxide from the body's cells.

RESPIRATION 3.4

Respiration is usually thought of in terms of "breathing" only, but it actually includes the utilization of oxygen and the various exchanges of gas which take place throughout the body as part of the metabolic process. For clarification, breathing is sometimes called "external" respiration, and the other aspects are identified as "internal" respiration.

The respiratory system is comprised of those parts of the body which are involved in the process of breathing: the lungs, the air passages leading to the lungs, and the rib cage, diaphragm and other muscles which help produce the movement of air into and out of the lungs.

The lungs can be thought of as being two elastic bags containing about 300 million distensible air sacs, or **alveoli**. The alveoli present a large, moist surface area to facilitate the exchange of gas between the blood in the lung capillaries, and the breathing mixture which has reached the alveoli.

Air travels to the lungs through the nasal passages and the mouth by way of the **trachea** (the main windpipe) which divides into the right and left **bronchi**. These tubular passages in turn divide into smaller bronchi, which themselves branch off into innumerable bronchioles, feeding air into the alveoli.

Breathing 3.4.1 Breathing is the result of a combined movement of the rib cage and the diaphragm, which increases or decreases the volume of the chest cavity. For inspiration, the ribs are raised and the diaphragm (which forms the bottom of the chest cavity) is lowered. In accordance with Boyle's Law, the pressure in the chest is decreased as the volume is increased, and air from outside the body—since it is at a relatively higher pressure—will move into the lungs. When the rib cage is lowered and the diaphragm raised, the volume is decreased and air is forced out of the lungs. However, no matter how hard a person might try, he will not be able to expel all of the air in his lungs. A **residual volume** of from 1 to 1.5 liters will always remain.

There are certain other terms used in measuring the capacity and activity of the lungs, with which a diver should be familiar—

Tidal volume is the amount of air moved in and out of the lungs during a single breathing cycle. Tidal volume may vary from breath to breath, and will usually range from about 0.5 liter when a person is at rest and breathing easily, to more than 2 liters when working and breathing heavily.

Vital capacity of the lungs is the greatest amount of air which can be moved in and out of the lungs in a single breath. It is measured by starting with the largest possible inspiration and then forcing out as much of the breath as possible, leaving only the residual volume. The vital capacity of the average man is between 4 and 5 liters.

Respiratory rate is the number of breathing cycles in one minute. A normal, average rate would be between 10 and 20 cycles per minute.

Respiratory minute volume (RMV, or minute volume) is the total volume of air moved in and out of the lungs in one minute. It is computed by multiplying the tidal volume by the respiratory rate. Since both of these factors are variable, RMV will vary (governed by the rate of activity) and can range from about 6 liters per minute to more than 100 liters per minute.

Inspiratory reserve volume measures the amount of air that can be forcibly added to the lungs after taking in a normal breath. Similarly, **expiratory reserve volume** is the amount of air that can be forcibly expelled after a normal expiration. These two reserve volumes will vary with the tidal volume; and, tidal volume plus both inspiratory and expiratory reserve volume will equal the vital capacity.

Respiratory dead space is that fraction of a breath which does not reach the alveoli and therefore does not participate in the gas exchanges in the lungs. This would include air remaining in the mouth, and the other air passages, which is brought in at the end of a breath and is pushed out ahead of the "used" air. The amount of dead space usually makes up about one-third of the tidal volume in normal, relaxed breathing.

Certain parts of a diver's apparatus, such as a mouthpiece or a full-face mask, can substantially add to the dead space, reducing the portion of the tidal volume which can actually be used in respiration. To com-

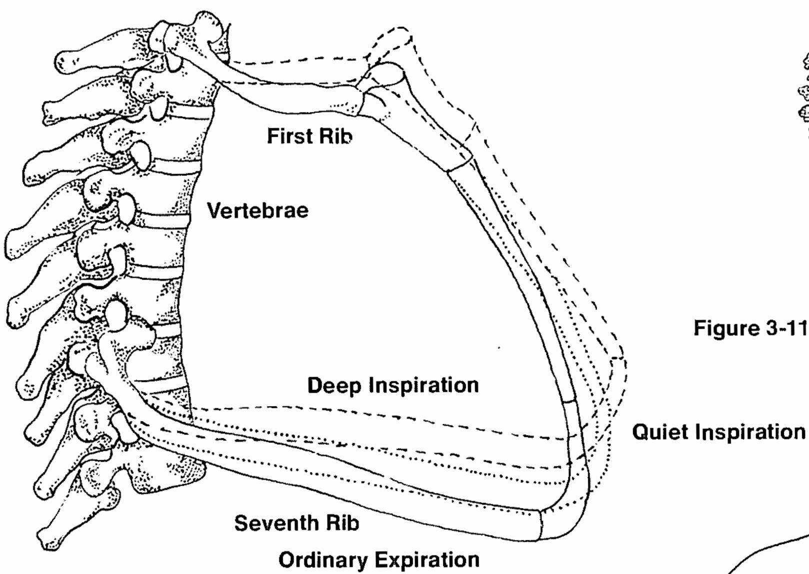


Figure 3-9 Rib cage movement during the breathing cycle.

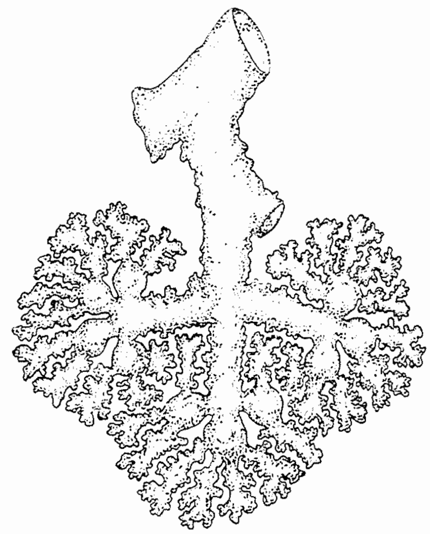


Figure 3-11 Detail of alveoli

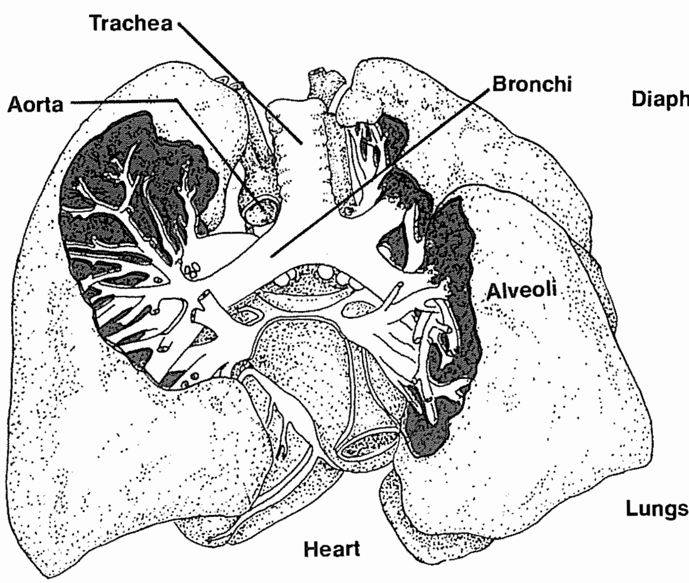


Figure 3-10 Dorsal view of heart and lungs showing pulmonary vessels and bronchial tree.

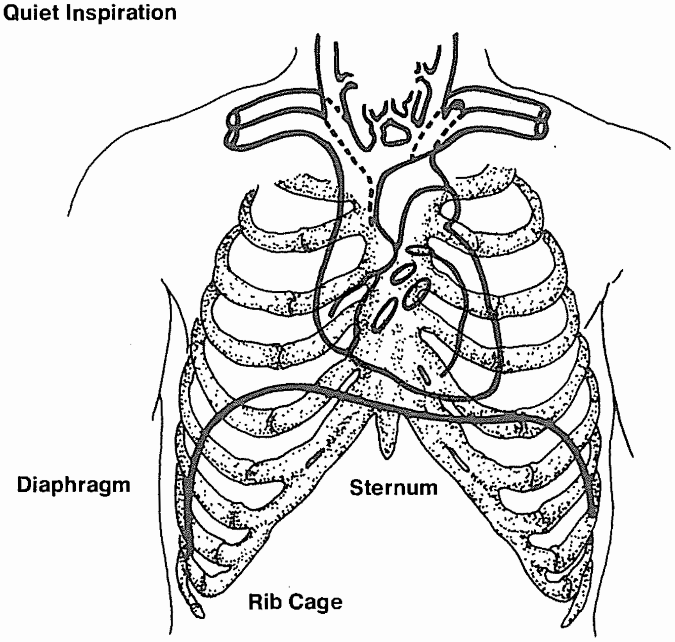


Figure 3-12

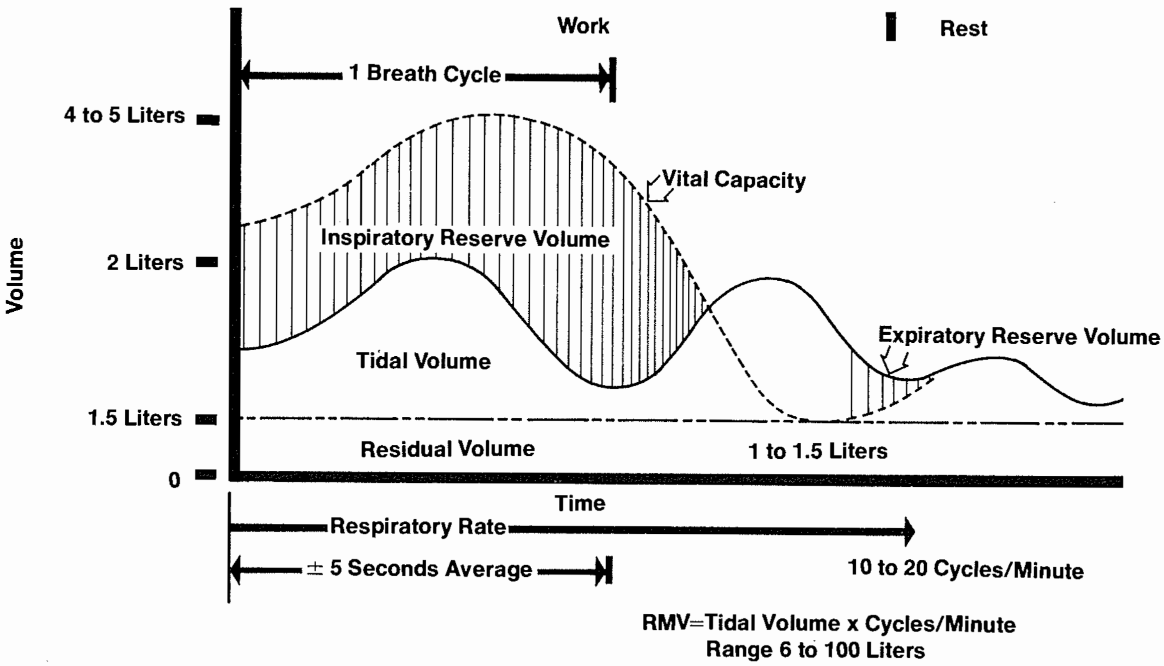


Figure 3-13 Lung volume

pensate for this, the diver must bring in more air with each breath. (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 inspiration, this used air will be drawn right back into the lungs unless the tidal volume is increased by one liter, to draw in the needed fresh supply.)

The air which reaches the alveoli is called alveolar air, to distinguish it from the air in the dead space. Alveolar air has a slightly different composition than air as finally exhaled from the body, which will have been mixed with the essentially unused air in the dead spaces during expiration.

The Breathing Cycle 3.4.2 Before air ever reaches the lungs, it will have been heated, moistened and cleansed of foreign particles and bacteria while being drawn across the moist mucous lining of the nasal passages. These processes help to protect the delicate tissues of the lungs from the injury and disease.

Once the air moves into the lungs, it comes into contact with the walls of the alveoli. Here, it is separated from the blood circulating in the lungs only by the membranous walls of the alveoli and the capillaries. The oxygen, driven by its relatively high partial pressure in the lung, is quickly dissolved by the moist lining of the alveoli and diffused through the membranes into the blood. The partial pressure of oxygen in the blood entering the lungs is relatively low, because much of the dissolved oxygen has previously been consumed in the various cells.

At the same time, the partial pressure of the carbon dioxide in this blood is high relative to that in the lungs, and a quantity of carbon dioxide will quickly diffuse into the area of lower partial pressure in the alveoli.

Example—

At atmospheric conditions, the partial pressure of oxygen in the blood entering the lungs is about 40 mm Hg (0.0526 atm), and the partial pressure of the carbon dioxide is about 46 mm Hg (0.0605 atm). The partial pressures for these two gases in the inspired air are about 158 mm Hg (0.208 atm) and 0.30 mm Hg (0.0004 atm) respectively; obviously, the partial pressure gradients of each gas are high and diffusion into and out of the blood will proceed almost instantaneously.

The partial pressures in alveolar air are almost the same as those for blood leaving the lungs since the exchanges of gas take place so rapidly that the composition of the inspired air is changed as it reaches the walls of the alveoli. This alveolar air, mixed with unused air in the respiratory dead spaces on the way out of the body, then becomes expired air. This has partial pressures of about 116 mm Hg (0.153 atm) for oxygen and 28.5 mm Hg (0.0376 atm) for carbon dioxide.

Oxygen Consumption 3.4.3 The concentration of oxygen and carbon dioxide in arterial blood is relatively constant, whether the body is at rest or at work, and is primarily determined by the partial pressures of the gases in the alveoli. When a working body requires greater quantities of oxygen, the additional supply is provided by an increase in the cardiac output. A corresponding increase in the respiratory minute volume provides more fresh air to match the larger flow of blood moving through the lungs.

A good measure of work-rate is oxygen consumption. This reveals the amount of oxygen actually being taken into the system and used. Oxygen consumption may vary from 0.25 liters per minute for a man at rest to more than 3 liters per minute when doing hard work (Figure 5-28). A trained athlete or a man in excellent physical condition can briefly maintain a rate of more than 4 liters per minute. It is also possible for a man to consume more oxygen than he can inspire for very brief periods, but in so doing he will build up an oxygen debt. His work-rate must soon be reduced to repay this debt and bring the levels of oxygen in the blood and tissues back to normal.

The number of molecules of oxygen actually consumed by the body in a period of time is not influenced by depth, although the volume of the gas will vary with the depth (in accordance with Boyle's Law). A man who is working hard enough to consume 2 liters of oxygen per minute at the surface would consume only 1 liter as measured at a depth of 33 feet (10 meters)—but he would still be using the same number of molecules. In order to permit accurate comparisons, oxygen consumption should be expressed in terms of volumes measured under "standard conditions." One set of standard conditions is 0°C, 760 mm Hg barometric pressure, and dry gas—designated by the abbreviation STPD (Standard Temperature and Pressure, Dry). Since the actual measurements are often made with expired gas, which is at body temperature and saturated, the measurements might be so identified by the abbreviation BTPS (Body Temperature, atmospheric Pressure, Saturated gas).

Carbon Dioxide Output 3.4.4. The production of carbon dioxide closely follows the consumption of oxygen. For every liter of oxygen consumed, a man will produce close to a liter of carbon dioxide. Just as with oxygen consumption, the volume occupied by the gas molecules will vary with depth. The actual number of molecules involved does not vary with depth.

The relationship between the amount of carbon dioxide produced and the amount of oxygen consumed can be expressed as a ratio called the respiratory quotient.

$$\text{Respiratory quotient} = \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}}$$

This can range from 0.7 to 1.0, depending upon a man's diet and the rate at which he is working. The average value for a working diver is about 0.85, which means that for every liter of oxygen consumed, 0.85 liters of carbon dioxide is produced.

Ventilation 3.4.5 The amount of air that a man must move in and out of his lungs is closely related to his oxygen consumption and carbon dioxide production. Under normal conditions on the surface, and under usual diving conditions (where the partial pressure of oxygen has been increased), a man's breathing rate will be determined primarily by his need to eliminate excess carbon dioxide. He could reduce his breathing rate and still get enough oxygen, but this might not remove sufficient quantities of carbon dioxide. To properly ventilate his lungs and the dead spaces of his equipment, an adequate flow of fresh air (measured at bottom conditions) is required.

The supply of air required for adequate ventilation of the lungs of a working diver can be calculated in advance, based on a general knowledge of the anticipated work-rate, the type of apparatus he will be using, and the amount of carbon dioxide in the breathing supply (See Chapter Six, VENTILATION).

Control of Breathing 3.4.6 Respiratory centers in the brain, sensitive to the level of carbon dioxide and acid in the blood, control the rate and volume of breathing. If these levels become too high the centers trigger an increase in breathing which will move a greater volume of air through the lungs until the carbon dioxide and acid levels are returned to normal.

Other sensing devices in the body, called peripheral chemoreceptors, monitor the level of oxygen and carbon dioxide in the blood leaving the lungs. When the oxygen partial pressure falls, the chemoreceptors send impulses to the respiratory center, signalling the need for an increase in breathing. However, a low oxygen level, by itself, may not increase the breathing rate until a dangerously low oxygen partial pressure has been reached.

Breathing rate and volume may also be influenced by factors other than those noted above. For example, exercise, heat, anxiety or other emotional states may trigger increases.

Breathholding and Hyperventilation 3.4.7 Most people can hold their breath between one and two minutes, but usually not much longer without training or special preparation. At some point during a breathholding attempt, the desire to breathe will become so intense that it can no longer be forestalled. This demand is signalled by the respiratory center responding to the increasing levels of carbon dioxide and acids in the blood, and by the chemoreceptors responding to the corresponding fall in the level of oxygen and rise in arterial carbon dioxide.

The repeated practice of breathholding to achieve an increase in time probably has as positive an effect on the will power to resist the demand to breathe, as it does on actually improving any physical capacities. However, the length of time that a man can hold his breath can be dramatically extended by two methods which are frequently used by free divers. These are

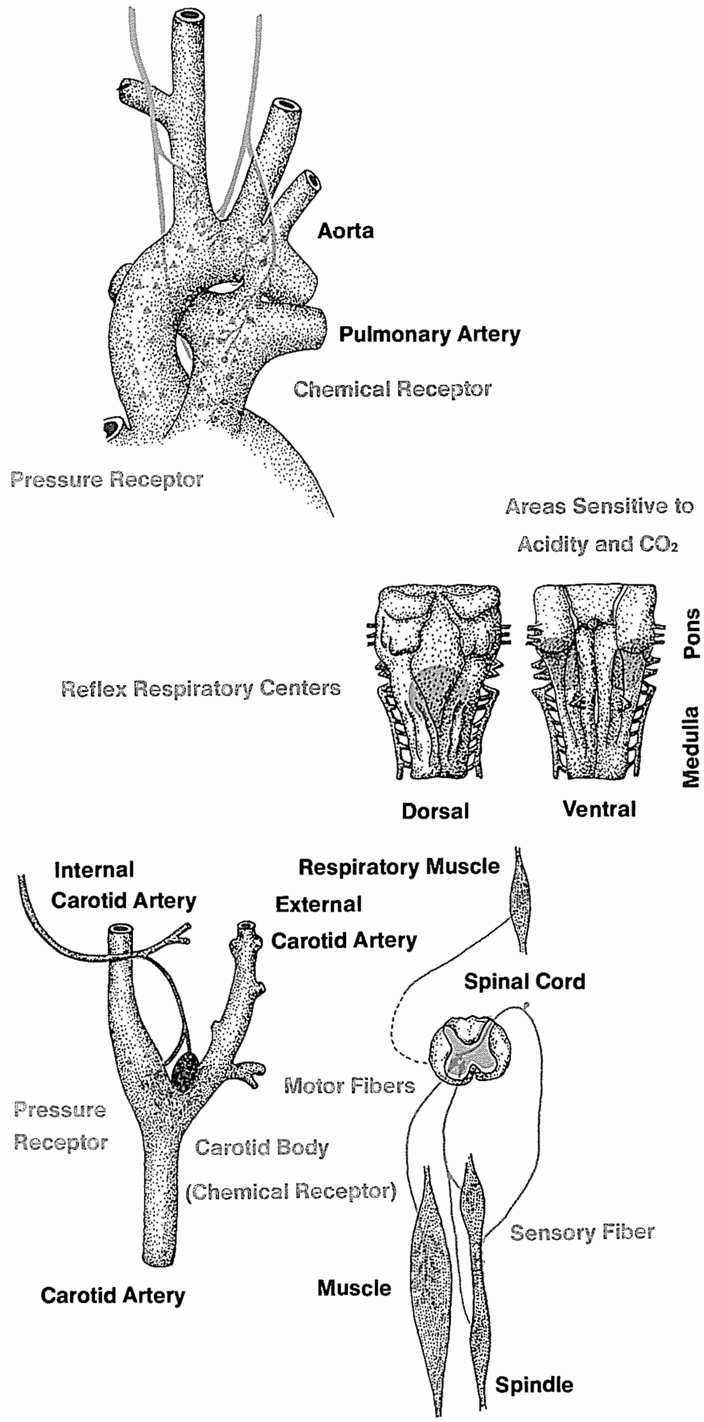


Figure 3-14 Regulation of breathing is controlled by the lower brain and other receptor and reflex centers. The medulla (lower brain) responds to increases in CO_2 pressure and acidity. Cells attached to the aorta, pulmonary artery and carotid artery act as both pressure and chemical receptors.

hyperventilation and breathing pure oxygen just before a dive.

Hyperventilation is breathing more than is necessary to eliminate the carbon dioxide produced by the metabolism. By over-ventilating the lungs, the free diver reduces the partial pressure of carbon dioxide in the blood below a normal level, and can therefore hold his breath longer while the carbon dioxide level is building up to the point at which the respiratory center will force resumption of breathing. The practice of hyperventilation should be approached with caution, since the carbon dioxide level provides the stimulus to breathe and causes the diver to feel air hunger.

If the carbon dioxide stores are ventilated below the stimulus level, there is little stimulus to breathe. While the period of breathholding is being prolonged because the diver experiences no discomfort, the oxygen partial pressure will progressively fall. Since low levels of oxygen do not force a powerful demand to resume breathing, the level of oxygen in the blood may reach the point at which the diver will lose consciousness before he feels a demand to breathe.

Hyperventilation can be unintentional as well as voluntary. It may be triggered by anxiety, and it can be experienced by normal individuals in any stress situation. For example, a diver using SCUBA for the first time is likely to hyperventilate to some extent because of his natural anxiety.

Hyperventilation can also cause hypocapnia, a condition resulting from low levels of carbon dioxide in the blood leaving the lungs. Symptoms of hypocapnia range from lightheadedness and a tingling sensation to muscular spasms and perhaps even loss of consciousness. The opposite condition to hypocapnia is hypercapnia, resulting from an excess of carbon dioxide when ventilation is inadequate (See Section 3.4.10).

Free divers who hyperventilate and breathe pure oxygen before a dive have markedly increased times for their dives. The breathing of oxygen puts a high concentration of the gas in the lungs which, in turn, keeps a safe quantity of oxygen in the blood for a longer period of time than if the lungs were filled with air. The current world record for underwater breathholding, achieved with the aid of these techniques, is more than 13 minutes. However, any diver should approach the use of such methods with extreme caution and do so only under competent supervision.

One of the greatest hazards of deep free diving is the possible loss of consciousness during ascent. Oxygen in the lungs during descent is compressed, and the partial pressure 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, however, the partial pressure of the remaining oxygen is reduced as the hydrostatic pressure on the body lessens. If the partial pressure drops below 0.16 atm., unconsciousness may result with its attendant dangers. This danger is further heightened when hyperventilation has eliminated normal body warning signs, and may occur even with prior oxygen breathing if the underwater stay is lengthy.

Breathing Resistance 3.4.8 The capacities of a diver's heart and lungs limit the workload that he can maintain. This limit will be reduced by any factor which decreases the effectiveness of his breathing or which makes it harder for him to breathe, which would necessarily absorb a portion of his available energy. The characteristics of the diving environment and the diving equipment will directly influence breathing effectiveness. Factors of particular importance are—

1. If the source of air is at a pressure lower than the pressure at the diver's lungs, he will have to exert energy to pull the air into his lungs. For example: if the demand regulator on an open-circuit SCUBA is located on the tanks (at the back of the diver's neck), it will be working under a lower pressure than his lungs (when he is swimming horizontally). While the pressure difference is not great (equal to about 15 cm of water, or about ¼ psi), the diver will still have to establish sufficient additional negative pressure in his lungs in order to draw air through the valve. If the regulator were placed below his chest (where it would be under slightly higher pressure), inhalation would be easier but exhalation would require more effort.
2. Excessive dead space contributes to the breathing effort by increasing the volume of

gas which must be moved with each breath in order to properly ventilate the lungs.

3. Equipment design may induce excessive resistance to the passage of breathing gas.
4. Increased density of the air when under pressure requires more effort to move it through the breathing apparatus and through the respiratory passages of the body than would be needed on the surface.

Hypoxia 3.4.9 The term hypoxia applies to any situation in which the tissue cells fail to receive or utilize enough oxygen. Hypoxia can result from such factors as—

1. Blockage or restriction of breathing as in obstruction of airway or asthma
2. Inadequate oxygen in the breathing mixture
3. Diseases of the lungs which inhibit diffusion of oxygen from the alveoli to the blood
4. Conditions in the blood (such as anemia or carbon monoxide poisoning) which interfere with the transport of oxygen
5. Circulatory impairment
6. Toxic conditions which prevent the cells from properly using the oxygen they receive

In dramatic instances, such as a complete loss of the air supply or a blockage of the trachea, the diver will immediately be aware of the problem and can try to correct the situation. However, any corrective action must be initiated at once, as the onset of hypoxia will be sudden and severe, leading rapidly to unconsciousness.

Other causes of hypoxia are more subtle, and the developing situation may go undetected by the diver himself. Additionally, since the brain is the first part of the body affected by hypoxia, the first symptoms may be similar to those of alcoholic intoxication, giving the diver a false sense of security or a feeling of euphoria as he proceeds on to unconsciousness.

The partial pressure of oxygen in the breathing mixture must remain above 0.16 atmospheres or hypoxia will be likely. The probable symptoms experienced with lower partial pressures are—

0.14 ata—first symptoms (drowsiness, inability to think clearly, lack of fine-muscle control)

0.12 ata—discomfort, rapid breathing

0.10 ata—some people will lose consciousness

0.06 ata—anyone will be unconscious; below this level, death may quickly ensue.

A diver can be supplied with a breathing mixture that has a lower percentage of oxygen than air, if the partial pressure of the oxygen at the operating depth will be maintained at 0.16 ata or higher. Breathing a mixture with 5% oxygen at 30 meters (4 ata) would be almost equivalent to breathing air at the surface (5% x 4 ata = 0.20 ata pp O_2). However, when a diver breathing such a mixture starts to ascend, the oxygen percentage must be increased to maintain an acceptable partial pressure or he will quickly become hypoxic, might lose consciousness and could die.

With the onset of hypoxia, certain regulatory mechanisms in the body will attempt to offset the shortage of oxygen by increasing the rate of blood supply. The resulting higher pulse rate, blood pressure and (possibly) increased breathing rate may help the situation. These changes may also serve as warning signs to a diver who otherwise might not be aware of the gradually developing symptoms of hypoxia.

The shortage of oxygen in the hemoglobin produces one visible sign of hypoxia; a general blueness (cyanosis) of the lips, nail beds and skin. Unfortunately, this is not likely to be noticed by the diver while at work and is not a reliable indicator of hypoxia even for the trained observer at the surface. The same sort of signs could be caused merely by prolonged exposure in cold water; and, conversely, if the hypoxia is caused by carbon monoxide poisoning (see Section 3.4.12) these parts of the body will tend to be redder in color than normal.

Since a particular danger of hypoxia is the inability to detect and diagnose the problem, prevention is an essential measure. The diver must know his oxygen requirements, and must ensure that these requirements will be met at all times throughout the dive.

Hypoxia is treated in the same manner as any serious interruption of the breathing process—

—administer oxygen or provide sufficient fresh air
—clear any obstructions from the airway, if necessary
—administer appropriate resuscitation, if necessary

If treatment is timely, recovery is usually prompt and complete. If treatment is delayed or ineffective, damage to the brain cells can be permanent and death may result. (See Chapter Eight, DIVING EMERGENCIES, for more detailed information on the treatment of this and other emergency situations.)

Excessive Carbon Dioxide 3.4.10 In diving operations, an excess of carbon dioxide in the tissues (hypercapnia) is generally the result of a build-up of carbon dioxide in the breathing supply or in the body as a result of—

—inadequate ventilation
—failure of CO_2 removal equipment (as in a closed or semiclosed SCUBA)
—increased CO_2 production during work or while under stress
—contamination of the breathing mixture

It has also been found in diving that carbon dioxide concentrations in the body which stimulate increased respiration are higher than normal. This rise in threshold level increases the hazard of hypercapnia and is most pronounced in the following situations—

—diving on air
—exertion while diving on air
—excessive resistance to breathing or excessive work of breathing
—inadequate respiratory drive to CO_2 is more typical of divers than non-divers

The most common source of hypercapnia is the diver's own metabolic processes, and the most common cause is the failure to properly ventilate the breathing apparatus. On occasion, through improper breathing techniques, a diver can even poison himself by inadequate ventilation of his own lungs. This can happen for example when a diver, trying to conserve his breathing supply, reduces his breathing rate below a safe level.

An excess of carbon dioxide has different chemical effects on the brain than does hypoxia, but it can result in similar symptoms such as confusion, an inability to think clearly, loss of consciousness and generalized convulsions which may be confused with oxygen poisoning. Serious and long-lasting damage is not as likely with carbon dioxide poisoning as with hypoxia, and a diver who has lost consciousness solely because of excess carbon dioxide can usually be revived by adequate ventilation with fresh air. Breathing an excess of carbon dioxide may increase the possibility of decompression sickness, and will speed the onset of oxygen poisoning.

The warning signals of approaching hypercapnia are likely to be more serious to the diver than the usual symptoms of hypoxia. The increasing level of carbon dioxide in the blood stimulates the respiratory center to increase the breathing rate and volume, and the rate of heartbeat is often increased. However, variables such as work-rate, depth and the composition of the breathing mixture may produce changes in breathing and blood circulation which could mask any changes caused by hypercapnia. For this reason, a diver must be particularly alert for such changes, and any marked change in his breathing comfort or cycle (such as shortness of breath or panting) must be taken as a warning.

Asphyxia and Strangulation 3.4.11 If a diver stops breathing entirely, or if he is breathing an atmosphere that is low in oxygen and high in carbon dioxide, he will soon become both hypoxic and hypercapnic. The term used to describe the presence of both conditions is asphyxia.

Hypoxia and hypercapnia do not always occur together. However, when hypoxia becomes severe enough to halt breathing, carbon dioxide will rapidly build up in the body and the resulting condition will be asphyxia.

A stoppage of breath due to injury or obstruction of the air passages is known as strangulation. This is a condition which has little to do with the nature of the breathing mixture, and can be caused by such factors as a crushing injury to the trachea or a laryngeal spasm. The tongue of an unconscious person may fall back into his throat, blocking the intake of air. Other causes of strangulation may include inhaled water, saliva or vomitus, or an airway obstruction caused by a foreign object such as food, chewing gum or a false tooth. A strangulation victim will often struggle violently, even if unconscious, in an attempt to breathe. Asphyxia is inevitable if uncorrected and brain damage and death will follow within a few minutes (See Section 8.2.1, Chapter Eight).

Carbon Monoxide Poisoning 3.4.12 Carbon monoxide is not found in any significant quantity in fresh air. When it does pollute the breathing supply (usually from engine exhaust in proximity to the compressor intake), even a concentration as low as .002 atmospheres can be fatal. Carbon monoxide is so highly toxic because it combines with hemoglobin 200 times more readily than does oxygen, displacing large quantities of oxygen and rapidly bringing about hypoxia. A concentration of carbon monoxide as low as .001 atmosphere will replace one-half of the oxygen which would normally be carried by the hemoglobin, even though the lungs may contain a normally ample supply of oxygen. Carbon monoxide poisoning also depends on the duration of exposure to the gas; very low levels breathed over a period of time can have the same effect as breathing higher levels over a short period.

The symptoms of carbon monoxide poisoning are almost identical with those of hypoxia, since it is in fact a condition of hypoxia caused by an interference with the normal transport of oxygen in the blood. One major difference, however, is that the victim will not display the blueness (cyanosis) that is typical of hypoxia. When combined with carbon monoxide, hemoglobin is even a brighter red than when combined with oxygen, and will bring an unnatural redness to the lips, nail beds and skin.

If the onset of the poisoning is gradual, the diver may experience a tightness across the forehead, headache and pounding at the temples, and, occasionally, nausea and vomiting. The usual symptoms of hypoxia —including confusion and disorientation—are not likely to be apparent to the diver.

A particularly treacherous factor in carbon monoxide poisoning is that conspicuous symptoms may be delayed until the diver begins to surface. This is because, while at the depth, the greater partial pressure of oxygen in the breathing supply will force more oxygen into solution in the blood plasma. Some of this additional oxygen will reach the cells, and some of it may forcibly displace carbon monoxide from the hemoglobin. During ascent, as the partial pressure of oxygen diminishes, the full effect of the carbon monoxide will be felt.

Carbon monoxide poisoning is treated in much the same manner as any respiratory problem; by providing quantities of fresh, pure air. However, if available, the administration of 2 atmospheres of pure oxygen is the treatment of choice. The additional oxygen will increase the amount of oxygen reaching the tissues in spite of the inactivated hemoglobin, and will also speed the rate at which the hemoglobin is purged of the carbon monoxide and returned to normal.

Breathing fresh air should eliminate most of the carbon monoxide from the blood, in a moderate case of poisoning, in a few hours. Breathing oxygen at increased pressure may substantially reduce this time.

BODY TEMPERATURE AND HEAT LOSS 3.5

The human body functions effectively within a relatively narrow range of internal temperature. The average, or "normal" level of 98.6°F (37°C) is maintained by natural mechanisms of the body, aided by artificial measures such as the use of protective clothing or air conditioning when external conditions tend toward extremes of cold or heat.

The metabolic processes of the body constantly generate enough heat each hour to warm 2 liters of ice-cold water to body temperature, and if doing heavy work, it may generate more than 10 times as much heat. If this heat were allowed to build up inside the body, it would soon reach a high enough level to actually damage the cells—approximately 105°F (41°C). In order to maintain internal temperatures at the proper level, the body must lose heat equal to the amount it produces.

This is accomplished in several different ways. The blood, 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 in the skin, cools the surface of the body as it evaporates, facilitating the transfer of heat from the blood to the surrounding air. If the body is working hard, and therefore generating greater than normal quantities of heat, the blood vessels nearest the skin will dilate to permit more of the heated blood to reach the body surfaces, and the sweat glands will increase their activity.

If the surrounding air is hot, the rate of heat transfer will be slower than in cool air, and if the humidity is high, evaporation of moisture from the skin will be greatly inhibited. For these reasons, a man cannot do as much work on hot, humid days as on cool, dry days. He soon reaches the point at which heat production cannot adequately be balanced by heat loss.

The maintenance of proper body temperature is particularly difficult for a diver working underwater. In warm tropical waters (above 86°F, 30°C) the cooling systems of the body will be ineffective and a diver may find himself approaching a state of heat exhaustion. High temperature waters are the exception in diving, however, and the principal temperature control problems encountered by divers will involve keeping the body warm. The high thermal conductivity of water coupled with the normally cool-to-cold waters in which the diver operates, can result in rapid and excessive heat loss. The effects can range from simple chilling to serious conditions of hypothermia (excessive cooling of the vital organs).

The body adapts to cold by attempting to keep the critical parts as warm as possible. The flow of blood to the skin and extremities is reduced, somewhat limiting heat loss while warm blood is concentrated in the vital organs. Women and fat men have a thermal advantage over thin men, at least when it comes to tolerating immersion in cold water. Also, a diver who is working hard and producing a great deal of body heat will be able to withstand the cold longer than a man at rest since it will take longer for his temperature to fall to an uncomfortable level.

In water temperatures below 72°F (23°C), the unprotected diver will be affected by excessive heat loss and become chilled within a short period of time. As the body temperature is reduced, he will first feel uncomfortable and then, as his body tries to increase heat production in the muscles, he will begin to shiver. From this point, if cooling continues, his ability to perform useful work may become seriously impaired. The hands lose dexterity, and the sense of touch is dulled. As shivering intensifies, it brings on a general lack of coordination and may even make it difficult for a SCUBA diver to keep his mouthpiece in place. It becomes increasingly difficult to concentrate, and the ability to think clearly is soon lost.

At extremely low temperatures, or with prolonged immersion, body heat loss will reach a point at which death will occur. In water of 42°F (6°C), an unclothed man of average build will become helpless within 30 minutes and will probably die within an hour. He could withstand immersion at 60°F (16°C) for about 2 hours. If he were wearing heavy, conventional clothing, these times could be more than doubled. A diver, wearing appropriate dress and thermal underwear or an exposure suit, can greatly offset the effects of heat loss under normal diving conditions and can work in very cold water for reasonable periods of time.

For exceptionally deep-diving certain aspects of heat loss problems are aggravated and require special consideration. The extreme pressures at great depths compress the insulating materials and reduce their effectiveness. Also, as the density of the breathing mixture is increased, the heat lost from the body with each exhalation becomes significant. At 180 meters, (590 feet) for example, a diver will lose as much heat through breathing as he will be generating (whether working or at rest). This is independent of any heat loss through other means. In order to permit a diver to work at great depths (or in exceptionally cold water), special diving suits, heated by circulating hot water, have been designed. These are included as an integral part of some of the more recent diving systems.

A diver who has become chilled must be brought out of the water before serious complications ensue, and must regain his normal body temperature as rapidly as possible. Merely covering him with a blanket will have little effect because his body will not be generating enough heat to provide warmth under the blanket. Depending upon the degree of chill, effective measures include exercise, hot drinks, a hot shower or warming by standing between two bonfires on the beach. The most efficient method—and the best to use in any severe cases—is a hot bath.

PRESSURE RELATED AILMENTS—DESCENT 3.6

The tissues of the body can withstand tremendous pressure: men have made actual ocean dives to 1000 f.s.w. (350 meters) and, in experimental situations, have been exposed to pressure equivalent to a dive of 1640 f.s.w. (500 meters). Small animals, such as mice, goats and monkeys, have withstood pressures equivalent to dives as great as 5577 f.s.w. (1700 meters).

The majority of the body is composed of virtually incompressible liquids, permitting external pressures to be evenly transmitted through all of the tissues. If air is supplied at approximately the same pressure as that surrounding the diver, the natural air spaces in the body, the lungs, the middle ear and the sinuses, will be in pressure balance with the body tissues and the external pressure.

The pressure-related problems which may arise as a diver descends in the water result when the pressure, either in these natural air spaces, or in certain items of equipment which put an air space next to the diver's body, cannot be equalized. The natural air spaces have vents which normally allow internal and external pressure to equalize. The lungs are vented by breathing, the middle ear and the sinuses are connected by air passages with the throat and nose. If these passages should become blocked—by the congestion of a head cold, for example—air trapped in the spaces cannot be equalized as the diver descends. This is also true of air trapped between the diver's skin and a piece of equipment. Because these spaces have rigid walls, this air cannot be compressed to equalize the pressure, and a situation may arise where body tissues, under higher pressure, will be forced into the space. This situation can be painful, and if the pressure imbalance is great enough, can result in ruptured blood vessels or other tissue damage. In diving, the general term applied to this type of problem is squeeze.

Squeeze affects only spaces which have rigid walls—whether inside the body or in a piece of equipment. Gas pockets in the intestine, for example, are not usually a problem on descent because they are easily compressed.

Ear and Sinus Squeeze 3.6.1 The middle ear is part of the auditory mechanism and includes an air space which is separated from the external ear canal by the ear drum. This space is vented to the throat by the eustachian tube. If pressure changes are rapid, equalization of pressure within the middle ear may lag slightly behind the change in external pressure. For example, when riding in a fast elevator, some people will experience a slight "popping" of the ears as the pressure inside catches up with the change of outside pressure. If the eustachian tubes are blocked, the relatively small pressure change in the elevator ride might result in mild discomfort for a passenger. In diving, where the pressure changes are significantly greater, a blocked eustachian tube can bring about problems ranging from severe pain to serious ear injury.

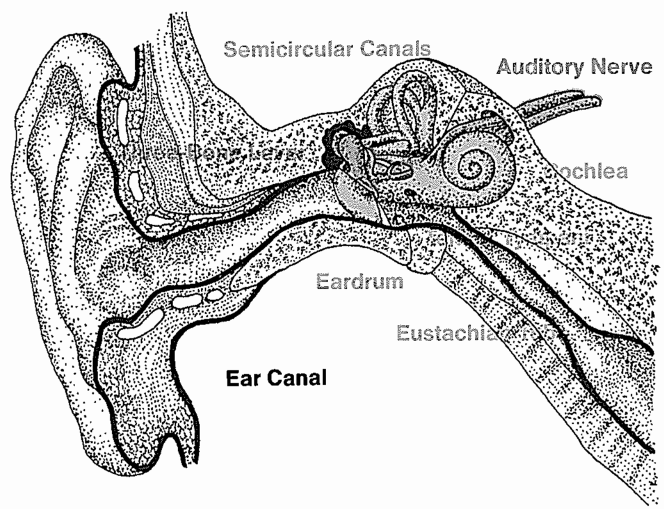


Figure 3-16 Sectional view of inner ear.

The effects of a pressure imbalance in the middle ear will be felt in two ways—

1. The outside pressure will push in on the ear drum, causing intense pain. If rising pressure is not checked (by stopping the descent) the ear drum may rupture.
2. The tissues that line the middle ear will swell into the space. Unless pressure balance is restored, blood or tissue fluids will fill the space. This will happen particularly in those instances where the pressure difference is not great enough to rupture the ear drum.

Ruptured ear drums or damaged tissues in the middle ear leave a diver vulnerable to infection, and will also prevent him from further diving until the damage is healed. A ruptured ear drum carries an additional hazard for a diver whose ears are in direct contact with the water—as in skin diving and some SCUBA work. The sudden rush of cold water into the middle ear can cause a brief but violent episode of vertigo. The diver can become completely disoriented, will probably become nauseated and may vomit. Fortunately, these symptoms will quickly pass as the water reaching the middle ear is warmed by the body.

The sinuses are located in hollow spaces in the bones of the skull. They are lined with mucous membrane and are connected to the nasal passages. If the connecting passages become blocked by congestion or swollen tissue, blood and tissue fluids will be forced into the sinus cavities causing intense pain and a possible hemorrhage of blood vessels.

Ear and sinus squeeze can often be prevented by not diving if any signs of nasal congestion or a head cold are apparent. The effects of squeeze can be limited during a dive by halting the descent and returning toward the surface a few feet. This will help restore the pressure balance. If the space cannot be equalized (by swallowing or blowing against a pinched-off nose), the dive must be aborted.

Tooth Squeeze 3.6.2 This results when a small pocket of trapped gas has been generated by decay or 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 squeezed into the space.

Thoracic (Lung) Squeeze 3.6.3 In making a breathhold dive, it is possible to reach a depth at which the air held in the lungs will be compressed to a volume smaller than the normal residual volume of the lungs. Should this happen, the blood and tissue fluids may be forced into the space, resulting in a thoracic squeeze. However, the volume of the lung at which thoracic squeeze occurs may be less than the residual volume because of blood shifting into

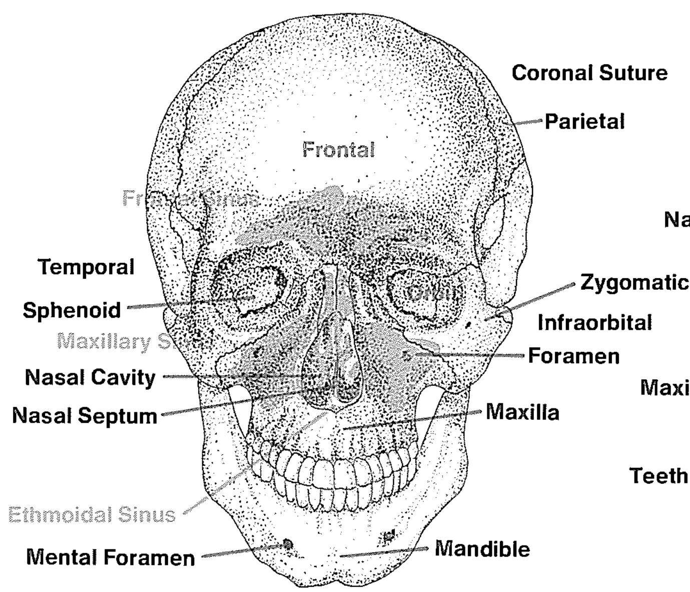
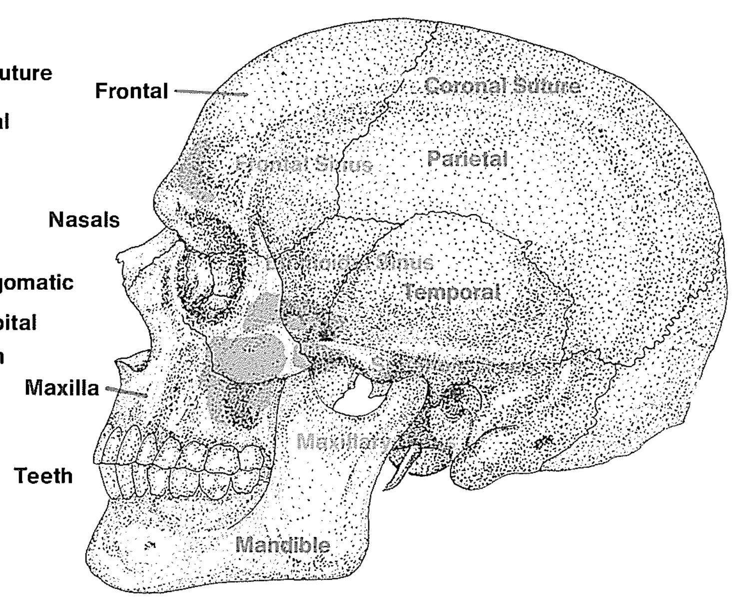


Figure 3-17 Frontal view of human skull with major sinus cavities projected on surface.



Lateral view of skull showing location of sinus cavities.

the pulmonary circuit and offsetting the pressure imbalance.

Theoretically, the average man with a total lung capacity of 6 liters could not breathhold dive beyond 30 meters (4 ata) as the air in his lungs at that point would be compressed to the residual volume (1.5 liters, average value). A man with an exceptional lung capacity could exceed that depth, but would eventually reach his own limit. In fact, this has yet to be demonstrated. A world record holder for breathhold skin diving, Navy Petty Officer Robert Croft, has an exceptional total lung capacity of more than 9 liters. In 1968, during a series of experimental dives, Croft reached 240 f.s.w. (73 meters) which is about 39 f.s.w. (12 meters) below his "computed" residual limit, and did not experience any symptoms of thoracic squeeze.

Face or Body Squeeze 3.6.4 If the air pressure in a surface-supplied face mask or helmet should suddenly become lower than that of the surrounding water—as in a failure of the air supply or from a rapid increase in depth—the tissues of the face or body can be seriously squeezed. This is a particular danger when working with the deep-sea diving dress, which encloses the head, neck and part of the upper chest in a rigid helmet and breastplate. Under normal conditions, the pressure in the helmet (and in the diving dress) will be in equilibrium with the outside pressure. However, if the air pressure suddenly drops, the outside pressure could force the air in the suit and helmet back up the air hose. In doing so, the non-rigid dress will collapse, squeezing the diver's body into the incompressible helmet, and if the pressure differential is great enough, this condition can become fatal. To help prevent a major body or face squeeze, all surface-supplied apparatus must be equipped with a safety non-return valve which will hold the gas in the suit at pressure in the event of a failure of the supply pressure. A diver may similarly become a victim of body and face squeeze if he should fall into deeper water without a corresponding increase in supply pressure (See Chapter Six for additional discussion).

Face masks used with SCUBA, goggles, and certain types of exposure suits can lead to problems of squeeze under some conditions. The pressure in a face mask can usually be equalized by exhaling through the nose, but this is not true of goggles which offer no way to equalize pressure. Goggles should not, therefore, be used for any diving except surface swimming. The most seriously affected tissues in an instance of face mask or goggle squeeze will be those of the eye and the eye socket. With exposure suits, air may be trapped in a fold in the garment and may lead to some discomfort and possibly a minor case of subcutaneous (beneath the skin) hemorrhage from pinching.

Nitrogen Narcosis 3.6.5 Most divers who breathe air under pressure will at some depth experience nitrogen narcosis (sometimes called "rapture of the deep"). Symptoms of this problem generally begin to appear at about 99 f.s.w. (30 meters) and progress rapidly beyond that depth. However, there is a wide range of individual susceptibility and some divers, particularly those experienced in deep operations with air, can often work as deep as 198 f.s.w. (60 meters) without serious difficulty.

The symptoms, although quite specific, are not always apparent to the individual. The nitrogen produces an intoxicating effect similar to that of alcohol. The narcosis is characterized by a slowing of mental activity, fixation of ideas, slowing of reaction time and general euphoria. The greatest hazard of nitrogen narcosis is that it may cause the diver to disregard the job or particularly his personal safety.

The mechanism by which nitrogen, under pressure, produces the narcotic effect is not known. The narcotic potency of nitrogen and other inert gases may be correlated with their relative solubility in fat (Meyer-Overton theory). The more soluble the gas, the greater the narcotic effect at a given partial pressure. For this reason, helium or neon—which are relatively insoluble in fat—are used as the inert gas in deep diving.

Oxygen Poisoning 3.6.6 Partial pressures of oxygen in excess of that encountered at normal atmospheric conditions may be toxic to the body. Oxygen toxicity is dependent upon both the partial pressure and the exposure time. In the range of 0.2 to 0.6 atm O_2, no toxicity is detectable regardless of exposure time. From approximately 0.6 to 1.6 atm O_2, with exposure times varying from days to hours, lung toxicity may occur which is first manifested as lung irritation and can lead to lung tissue damage if the exposure is continued. At partial pressures of 1.6 atm O_2 and higher, central nervous system oxygen toxicity occurs before lung toxicity produces symptomatic damage. Onset of CNS symptoms such as convulsions can occur in hours or minutes. Although a high concentration of oxygen produces noticeable effects upon the respiratory and central nervous systems, it also poisons many other systems' cells as well.

The susceptibility to central nervous system oxygen poisoning varies somewhat from person to person. The use of an "oxygen tolerance test" for diving training candidates is intended to identify those whose sensitivity to oxygen is unusually high. Individual susceptibility will also vary from time to time. A major external factor contributing to the development of oxygen poisoning is the presence of a high level of carbon dioxide in the breathing mixture from a contaminated gas supply, or as a consequence of heavy exertion or inadequate ventilation.

Experience and experimental investigation have shown that most divers, when performing heavy exercise, will be in danger of CNS oxygen poisoning when the partial pressure of oxygen in the breathing mixture is 1.6 atmospheres or greater. The air diver seldom encounters oxygen partial pressures above this level since it represents a depth of over 200 f.s.w. (60 meters) and problems of CO_2 retention and nitrogen narcosis tend to limit the maximum air depth. His greatest opportunity for being exposed to the potential of oxygen poisoning is during recompression treatment or surface decompression using oxygen. For this reason, it is essential that the diver be constantly monitored inside the chamber for the related symptoms of oxygen poisoning.

Sometimes early evidences of oxygen poisoning appear before convulsions. If recognized, these 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, in the approximate order of their likelihood of occurrence, include—

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

—Nausea—This may come and go periodically.

—Dizziness

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

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

—Anxiety and confusion

—Unusual fatigue

—Incoordination—Clumsiness, etc.

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

Convulsions are the most important consequence of poisoning due to excess oxygen. Treatment consists of the following procedures—

1. Do not restrain the man except to prevent him from harming himself against the chamber.
2. Remove the oxygen breathing mask.
3. Insert a soft object (other than a finger) between the teeth to prevent tongue chewing.
4. Wait. The convulsion will almost always cease in a few minutes.

NITROGEN ABSORPTION 3.7

The average human body, at sea level, contains about one liter of dissolved nitrogen. All of the body tissues are saturated with the gas, at a partial pressure equal to the partial pressure of nitrogen in the alveoli—about 570 mm Hg (0.75 ata). If the partial pressure of inspired nitrogen should change because of a change in the pressure or the composition of the breathing mixture, the pressure of the nitrogen dissolved in the body will attain a matching level. Additional quantities will be absorbed, or some of the gas will be eliminated, until the nitrogen partial pressure in the lungs and in the tissues are in balance.

In accordance with Henry's Law, the amount of nitrogen which will be absorbed or released is almost directly proportional to the change in partial pressure. If one liter of nitrogen is absorbed at a pressure of one atmosphere, then two liters will be absorbed at two atmospheres (10 meters depth), and three liters at three atmospheres. The additional nitrogen in the lungs is quickly dissolved into the blood and carried throughout the body. Wherever the blood passes tissues that are not saturated, where the partial pressure of nitrogen is lower than that which is presently in the blood, some of the gas will diffuse into those tissues. The partial pressure in the blood will therefore be somewhat reduced, and as it once again passes through the lungs, it will absorb more nitrogen, which will then be carried on to the still-unsaturated tissues. This cycle will continue until all of the tissues of the body, and the blood as well, reach equilibrium with the partial pressure of the nitrogen in the lungs.

The rate at which different portions of the body become saturated will vary. Some areas have a relatively poor blood supply, and will become saturated more slowly than others. Some body tissues hold more nitrogen per unit volume than others, and it will take more time for the blood to supply them with enough nitrogen to reach the point of saturation. Fatty tissues, for example, will absorb about five times as much nitorgen as will watery tissues and, if provided with an equivalent blood supply, they will take much longer to become saturated. Fatty tissues with a poor blood supply will require even more time to reach saturation.

For all body tissue to become saturated with nitrogen, an exposure of about 24 hours to the higher partial pressure is required. The length of time seems to be independent of the quantity of nitrogen involved in the process: it will take the body 24 hours to become saturated with three liters of nitrogen at 20 meters (three ata) and an identical period of time saturated with five liters at 40 meters (five ata). The rate of absorption, in every part of the body, will be high at the beginning of the process, since the pressure gradient will be high, gradually reducing as the partial pressures in the lungs and the tissues approach equilibrium.

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

DESATURATION 3.8

The process of desaturation is the reverse of saturation. If the partial pressure of the gas in the lungs is reduced, either through a change in pressure or a change in the breathing medium, the new pressure gradient will induce the nitrogen to diffuse from the tissues to the blood, from the blood to the gas in the lungs, and then out of the body with the expired breath. Some parts of the body will desaturate more slowly than others for the same reasons that they saturate more slowly—poor blood supply, or a greater capacity to absorb the gas.

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

To illustrate—if a diver is working at a depth of 30 meters, he will be under a total pressure of 4 atmospheres. The partial pressure of the nitrogen in the air he is breathing will be approximately 3.2 atmospheres (80% of 4 ata). If his body is saturated with nitrogen, the partial pressure of the nitrogen in his tissues will also be 3.2 atmospheres. He may easily ascend a few feet, slightly reducing the partial pressure of the inspired nitrogen, and some of the gas will diffuse from his blood and be exhaled. If he were to remain at that depth, eventually all of his tissues would reach a new level of saturation, at the reduced partial pressure of the inert gas.

But if this diver were to quickly ascend to the surface, the total pressure outside his body of one atmosphere will be well below the 3.2 atmosphere value for the partial pressure of nitrogen throughout his body, and the tissues will be supersaturated. The gas will come out of solution faster than the bloodstream can move it to (and through) the lungs, and bubbles of nitrogen will form in the tissues and blood resulting in a condition known as decompression sickness. These bubbles can put pressure on nerves, damage delicate tissues and block the flow of blood to vital organs.

Symptoms may range from skin rash to mild discomfort and pain in the joints and muscles, to paralysis, numbness, hearing loss, vertigo, unconsciousness, and in extreme cases, death.

Decompression 3.8.1 The blood and tissues of the body can apparently hold gas in a supersaturated solution to some degree before bubbles will begin to form. This permits a diver to ascend a few feet without experiencing decompression sickness, while allowing some of the excess gas to diffuse out of the tissues and be passed out of his body. By progressively ascending in increments, and then waiting for a period of time at each level, the diver will eventually reach the surface without experiencing decompression sickness.

In actual diving practice, a diver very seldom will remain at depth long enough to become fully saturated with nitrogen. In a short dive, only those tissues which saturate rapidly will absorb any appreciable quantity of the gas, and they will desaturate easily. The standard decompression tables, developed from the researches of Haldane and various Navy test programs, have been composed to provide guidelines for controlled decompression for a wide range of diving circumstances. The factors involved include such considerations as depth and bottom time of the dive, and whether or not the diver has made more than one dive within a 12 hour period, all of which will have some influence upon the quantity of nitrogen which will have been absorbed. The established decompression tables (Chapter Seven) must be rigidly followed to insure maximum diver safety. Changes in decompression procedure shall be permitted only under the advice of a Diving Medical Officer or in situations of extreme emergency.

Not all decompression is necessarily carried out by staged ascent to the surface. If the depth of the dive is less than 33 f.s.w. (10 meters) no stops or staged decompression is required. Also, within certain limits, a diver can be brought out of the water, repressurized in a chamber, and then decompressed on the surface. This is a useful procedure when the surface support unit must move quickly, or when the in-water conditions are particularly hazardous.

The use of pure oxygen during decompression can reduce the time which will be required for controlled decompression. If used, pure oxygen will significantly reduce the partial pressure of the nitrogen in the alveoli, creating a higher pressure gradient than would otherwise be present.

Although all USN decompression procedures have been thoroughly tested in the laboratory and field, adherence to procedures and compliance with the standard tables does not guarantee that a diver will avoid decompression sickness. There are a number of individual differences and environmental factors which may influence development of decompression problems, in spite of all precautions. These include age, degree of obesity, excessive fatigue, lack of sleep, alcoholic indulgence, or anything which, in general, contributes to a poor physical condition or poor circulatory efficiency.

OTHER PRESSURE RELATED AILMENTS —ASCENT 3.9

As the diver ascends, gas in his body or apparatus will expand in accordance with Boyle's Law. If this expansion is not accommodated or controlled, the diver might encounter any of several serious and painful disabilities. These include—

- —gas embolism
- —emphysema
- —pneumothorax
- —intestinal or stomach cramps

A gas embolism is caused by excess gas pressure inside the lungs. It is most likely to develop during an improperly executed rapid ascent, as in a case of blow-up or when making an emergency free ascent. Additionally, if the diver should try to hold his breath during the ascent, the increasing gas pressure in the lungs can rupture the alveoli and lung capillaries, forcing bubbles of gas directly into the blood stream These bubbles may then be carried throughout the circulatory system, and will continue to expand as the ascent continues. If any become too large to pass through the blood vessels, an obstruction, or embolus will form and block the proper flow of blood. A traumatic gas embolism may be avoided by breathing normally during ascent, or, if the ascent is made without a gas supply, by continually exhaling the expanding gas that is already in the lungs.

Interstitial Emphysema involves an entry of gas into the interstitial tissues in the lungs and, like gas embolism, it can arise as a tear of lung tissue if the diver fails to adequately exhale during an ascent. This condition may accompany a gas embolism, or it may occur separately. **Subcutaneous emphysema** results from the expansion of gas which has leaked from torn tissue into the subcutaneous tissues. **Mediastinal emphysema** is a condition whereby gas has been forced through torn lung tissue into the loose mediastinal tissues in the middle of the chest, around the heart, the trachea and the major blood vessels. (This is not to be confused with the emphysema of old age or excessive smoking.)

Pneumothorax results from gas being forced between the lungs and the lining of the chest cavity. Its increasing volume as the diver ascends collapses the lung and may displace the heart thus compromising circulation.

Pockets of gas may form in the intestines as a result of normal digestive processes, or the diver may swallow gas which becomes trapped in his stomach. These conditions could result in painful cramps during ascent, but in most cases the expanding gases will purge themselves through the natural body vents.

PHYSIOLOGICAL HAZARDS FROM MUNITIONS 3.10

Divers frequently work with explosive materials or, if involved in combat swimming, may themselves become the target of explosives. An explosion is basically 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 propagating 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. At the same time, since the human body is also for the most part water and incompressible, an underwater shock wave will pass through the body with little or no damage to the solid tissues. However, the air spaces of the body, even though they may be in pressure balance with the ambient pressure, will not readily transmit the overpressure of the shock wave. As a result, the tissues which line the air spaces will be subject to a violent fragmenting force at the interface between the tissues and the gas.

The amount of damage to the body will be influenced by a number of factors. These include the size of the explosion, the distance from the site, and the type of explosive (some produce very rapid expansion while in others, the expansion progresses more slowly). In general, larger, closer and slower developing explosions are more hazardous. The depth of water and the type of bottom, which can reflect and amplify the shock wave, may also have an effect. Under "average" conditions, a shock wave of 300 psi or greater will cause injury to the lungs and the intestinal tract. A shock wave of this magnitude might be experienced from the explosion of a 1 pound (0.454 kg) charge, with the diver at 48 feet (15 meters) from the blast. A diver 48 feet from the explosion of a 600 pound (272 kg) charge would be subjected to a shock wave of 2,180 psi (6390 kg/cm^2).

The degree of injury in part will also be determined by the degree to which the diver's body is submerged. For an underwater blast, any part of the body which is out of the water will not be affected. Conversely, for an air blast, the deeper the diver, the better he will be protected. A diver who anticipates a nearby underwater explosion should try to get as much of his body out of the water as possible. If he must remain in the water, his best course of action is to float, face up, putting the thicker tissues of his back between the explosion and the vulnerable sites. ■

CHAPTER FOUR

OPERATIONS PLANNING

Figure 4-1 Members of a deep-sea diving team study the layout of a sunken minesweeper during a salvage training operation.

The success of any diving mission is directly related to careful and thorough planning. The nature of each operation will determine the scope of the planning effort, but certain considerations will apply to every operation:

- —Divers should not be used if the objective can be more safely and efficiently accomplished by another means.
- —Bottom time is always at a premium and any planning inputs which will conserve bottom time or increase the effectiveness of the diver should be given high priority.
- —Diving operations must not be conducted under extreme environmental conditions or whenever the safety of the divers or of the support facility will be jeopardized.
- —Divers must at all times be given protection against hazards, extremes of temperature, and dangerous pollution.
- —The availability of emergency assistance, both from within the diving unit and from outside sources as necessary, must be insured.
- —Equipment and supplies must be appropriate and adequate.
- —An operation that may be delayed for reasons that were not previously anticipated may well become an operation that is a failure. Changing weather conditions or threatened enemy action, for example, may prevent resumption of an interrupted or postponed operation. Careful planning is the best insurance against unnecessary disruption.

This chapter provides a comprehensive guide to effective dive planning for any size of operation. The material is organized for clarity into eight separate sections which form the proper sequence of steps in the planning process (Figure 4-2).

Steps in Planning of Diving Operations

1. DEFINE OBJECTS
2. COLLECT AND ANALYZE DATA
3. ESTABLISH OPERATIONAL TASKS
4. SELECT DIVING TECHNIQUE
5. SELECT EQUIPMENT AND SUPPLIES
6. SELECT AND ASSEMBLE THE DIVING TEAM
7. MAKE FINAL PREPARATIONS AND CHECK ALL SAFETY PRECAUTIONS
8. START OPERATION

Figure 4-2 Planning Sequence

The chapter also presents a series of suggested work-sheets and check lists which may serve as a basis for the preparation of detailed work-sheets for use in specific operations. The general subject of records keeping and reporting, which is a continuing responsibility at all stages of an operation, is covered in Appendix B.

DEFINE OBJECTIVES 4.1

Establish a clear statement of the objective: **why** is the operation being undertaken, and **what** is to be accomplished. This statement can be brief and specific.

Example:

"Locate, recover and deliver lost anchor to USS SMITH at Pier A."

The statement of the objective could be of a more general nature.

Example:

"Assemble all possible data on underwater conditions in the vicinity of Point X."

COLLECT AND ANALYZE DATA 4.2

A body of pertinent information should be assembled and studied as suitable to each particular operation. This will aid in:

- selection of technique, equipment and divers.
- identification of potential hazards and the need for emergency diving procedures.
- making allowances for contingencies.

The extent and type of information which must be gathered will be influenced by such factors as the size of the operation, the location of the diving site, and the time of year. Some operations will be of such a recurring nature that most of the required information will already be at hand. An example of such an assignment might be the removal of a propeller from a particular class of ship, located in the shipyard where the diving team is regularly stationed. However, for even such a "standard" operation, there is always the possibility that the ship in question may have been modified and might require a change in procedure or the use of special tools. This possibility should not be overlooked during the planning effort.

Some operations will require the collection of a great deal of information in advance. For example, in planning for the salvage of a sunken or stranded vessel, the diving team will need to know about the construction of the ship, the type and location of cargo, the type and location of fuel, the reason for the sinking or stranding and the nature and degree of damage sustained. The sources of such information may include ship's plans, cargo manifests and loading plans, interviews with witnesses and survivors, photographs, and official reports of similar accidents.

If the operation is to involve the recovery of an object from the bottom, the team will need to know at least the dimensions and weight of the object. Additional useful information (as available), might include floodable volume, established lifting points, construction material, length of time on the bottom, probable degree of imbedment in mud or silt, and the type and degree of damage to the object. Combined, this data will help define the type of lift to be used (boom, floating crane, lifting bags, pontoons), will indicate the need for high-pressure hoses to jet away mud or silt, and will help determine the disposition of the object after it is brought to the surface. Proper planning may find the object too heavy to be placed on the deck of the support ship, therefore specifying the need for a barge or heavy towing equipment.

For any operation which will involve a search for an object or underwater site, data gathered in advance will help to limit the area of the search and minimize the time required for the search. This is most important, since underwater searching by divers is inefficient and can add to the hazards of an operation. The type of information useful in narrowing the area of a search—using the loss of an aircraft as an example—would include: last known heading and altitude, speed, radar tracks plotted by ships or shore stations, tape recordings or radio transmissions, and eyewitness accounts.

Whenever the object of a search has been found, the site should be marked with a buoy which has been rigged in advance, ready for immediate use. A more complete discussion of the types of searches conducted in the Navy and the planning effort associated with each will be found in the U.S.N. Search Manual, NAVSHIPS 0994-010-7010.

Certain information must be collected as an aid in identifying hazards. For example, if a diver is to be working around a ship (whether for salvage or for simple inspection of the hull), he must know the location of all sea-suction and discharge points, and of propellers, rudders, diving planes and sonar transducers. If working in or near a damaged ship, divers must be informed of the kinds and locations of its cargo and the possibility of toxic or explosive fumes in its compartments or tanks. A diver should know in advance what sort of underwater conditions to expect, ranging from temperature to the type of marine growth common to the area. Information about conditions on the surface is equally important. Extreme weather conditions jeopardize the safety of the divers and the unit, and even moderate changes in the weather may cause changes in the work schedule.

Figures 4-3 and 4-4 are sample check-lists developed to gather data for the location and recovery of an object. Figure 4-4 serves to emphasize the type of data which may be required and Figure 4-3 indicates the wide range of possible data sources.

Most of the data gathered in the planning phase of an operation will come from outside sources or surface observations, and will be gathered long before the actual diving phase begins. However, if time and conditions permit, preliminary dives by senior, experienced members of the team can be of great value in refining the data base and in improving the dive plan.

For all diving operations, data should be collected and analyzed in the following general categories—

- Surface conditions
- Underwater conditions
- Resources
- Assistance and Emergencies

Surface Conditions 4.2.1 Conditions on the surface in the operating area will affect both the divers and the members of the team working topside. These conditions, influenced by the location, the time of year

PLANNING DATA SOURCES

Air Almanac
Coast & Geodetic Survey Charts
Coast Pilot Publications
Cognizant Command
Communications Logs
Computer Data
Construction Drawings
DECCA Readings
DRT Tracks
Electronic Analysis
Equipment Ops. Manuals
Flight or Float Plan
Flight or Ship Records
Hydrographic Publications
Light Lists
Local Yachtsmen/Fishermen
Log books
LORAN Readings
Nautical Almanac
Navigation Text (Duttons/Bowditch)
NAVOCEANO Data
Notices to Mariners
OPORDERS
Photographs
Radar Bearings
RDF Bearings
Sailing Directions
Ships Equipment
Ships Logs & Records
Ships Personnel
SITREP
SINS Records
SONAR Readings and/or Charts
TACAN Readings
Tapes
Test Records
Technical Reference Books
Tide Tables
U.S.N. Instructions
Visual Bearings
Weather Reports
Witnesses

Figure 4-3 Planning Data Sources

and the weather, include wind, waves, tide, current, cloud cover, temperature, visibility, and the presence of other ships.

Normal conditions for the area of operations can be determined from published tide and current tables, sailing directions, notices to mariners, and special charts which show seasonal variations in temperature, wind and ocean currents.

Weather reports and long-range weather forecasts must be studied to determine if conditions will be acceptable for diving, and weather reports must be continually monitored while an operation is in progress.

OBJECTIVE CHECKLIST

Mission Title ____________

Known Location ____________ (Lat/Long)

Planner ____________ Date ____________

Planning Phase (check One) ☐ Preliminary ☐ Prior to Search ☐ Prior to DiveOps

OBJECT DEFINITION

Basic Description:

Type ____________ Mfg. ____________

I.D. Number ____________ Date Mfg. ____________

Material of Construction ____________

Operational Service ____________

Command ____________

Weight ____________ Length ____________

Height ____________ Width ____________

Power ____________ Color ____________

Floodable Volume ____________

Mission ____________

Departure Point ____________ ETD ____________

Destination ____________ ETA ____________

Course ____________ True ____________ Mag ____________

Navigation Equipment Aboard ____________

____

Safety Equipment Aboard ____________

____

Last Contact ____________

Last Recorded Altitude/Depth ____________

Last Recorded Speed ____________ Indicated

____________ Ground

Range ____________ Reserve Range ____________

Crew ____________

Other Personnel ____________

Time of Incident ____________

Cause of Incident ____________

Description of Incident ____________

____

Other Data ____________

____

____

ON-SITE INSPECTION

Location Marked ____________

Inspection Findings ____________

____

____

____

Figure 4-4 Objective Checklist

Diving should be discontinued if sudden squalls, heavy seas, unusual tide, or any other condition that, in the opinion of the Commanding Officer, jeopardizes the security of the mooring.

The most critical weather factor is the state of the sea (Sea State Chart Appendix C.). Wave action can affect everything from the stability of the mooring to the vulnerability of the crew and divers to seasickness or injury. Unless properly moored, a ship or boat will drift or swing around an anchor, greatly increasing the possibility of fouled lines and often dragging a diver along with it. Because of this, any vessel being used to support surface-supplied or tended diving operations must be secured by at least a two-point moor. A four-point moor, while more difficult to set, is preferable.

Divers are not particularly affected by the action of surface waves unless operating in surf, in shallow waters, or if the waves are exceptionally large. Below a certain depth (which will vary with the surface conditions) a diver will not be aware of any wave action. However, surface waves may well become a problem when the diver enters or leaves the water, as well as during decompression stops near the surface.

Effective dive planning must provide for extremes of temperature which may be encountered on the surface. These will normally be more of a problem for tending personnel than for a diver, although any reduction in the effectiveness of the surface crew may endanger the safety of a diver. The particular problems which must be guarded against are:

- —Sunburn
- —Windburn
- —Frostbite
- —Heat exhaustion

In cold, windy weather, the "wind chill factor" must also be considered. Any movement of cold air over exposed areas of skin will have an effect equivalent to that of much colder air. For example, if the actual temperature is 35 degrees Fahrenheit and the wind velocity is 35 mph, the equivalent chill temperature is 5 degrees Fahrenheit (Figure 4-5).

TEMPERATURE

Degrees Fahrenheit (Degrees Celsuis)

WIND MPH	40 (4)	35 (2)	30 (-1)	25 (-4)	20 (-7)	15 (-9)	10 (-12)
	EQUIVALENT CHILL TEMPERATURE, °F (°C)						
5	35 (2)	30 (-1)	25 (-4)	20 (-7)	15 (-9)	10 (-12)	5 (-15)
10	30 (-1)	20 (-7)	15 (-9)	10 (-12)	5 (-15	0 (-17)	-10 (-23)
15	25 (-4)	15 (-9)	10 (-12)	0 (-17)	-5 (-21)	-10 (-23)	-20 (-29)
20	20 (-7)	10 (-12)	5 (-15)	0 (-17)	-10 (-23)	-15 (-26)	-25 (-32)
25	15 (-9)	10 (-12)	0 (-17)	-5 (-21)	-15 (-26)	-20 (-29)	-30 (-34)
30	10 (-12)	5 (-15)	0 (-17)	-10 (-23)	-20 (-29)	-25 (-32)	-30 (-34)
35	10 (-12)	5 (-15)	-5 (-21)	-10 (-23)	-20 (-29)	-30 (-34)	-35 (-37)
40	10 (-12)	0 (-17)	-5 (-21)	-15 (-26)	-20 (-29)	-30 (-34)	-35 (-37)

	5 (-15)	0 (-17)	-5 (-21)	-10 (-23)	-15 (-26)	-20 (-29)	-25 (-32)
	EQUIVALENT CHILL TEMPERATURE, °F (°C)						
5	0 (-17)	-5 (-15)	-10 (-23)	-15 (-26)	-20 (-29)	-25 (-32)	-30 (-34)
10	-15 (-26)	-20 (-24)	-25 (-32)	-35 (-37)	-40 (-40)	-45 (-43)	-50 (-46)
15	-25 (-32)	-30 (-34)	-40 (-40)	-45 (-43)	-50 (-46)	-60 (-51)	-65 (-54)
20	-30 (-34)	-35 (-37)	-45 (-43)	-50 (-46)	-60 (-51)	-65 (-54)	-75 (-60)
25	-35 (-37)	-45 (-43)	-50 (-46)	-60 (-51)	-65 (-54)	-75 (-60)	-80 (-62)
30	-40 (-40)	-50 (-46)	-55 (-48)	-65 (-54)	-70 (-57)	-80 (-62)	-85 (-65)
35	-40 (-40)	-50 (-46)	-60 (-51)	-65 (-54)	-75 (-60)	-80 (-62)	-90 (-68)
40	-45 (-43)	-55 (-48)	-60 (-51)	-70 (-57)	-75 (-60)	-85 (-65)	-95 (-71)

	-30 (-34)	-35 (-37)	-40 (-40)	-45 (-43)	-50 (-46)	-55 (-48)	-60 (-51)
	EQUIVALENT CHILL TEMPERATURE, °F (°C)						
5	-35 (-37)	-40 (-40)	-45 (-43)	-50 (-46)	-55 (-48)	-60 (-51)	-70 (-57)
10	-60 (-51)	-65 (-54)	-70 (-57)	-75 (-60)	-80 (-62)	-90 (-68)	-95 (-71)
15	-70 (-57)	-80 (-62)	-85 (-65)	-90 (-68)	-100 (-73)	-105 (-76)	-110 (-79)
20	-80 (-62)	-85 (-65)	-95 (-71)	-100 ,-73)	-110 (-79)	-115 (-82)	-120 (-85)
25	-90 (-68)	-95 (-71)	-105 (-76)	-110 (-79)	-120 (-85)	-125 (-87)	-135 (-93)
30	-95 (-71)	-100 (-73)	-110 (-79)	-115 (-82)	-125 (-87)	-130 (-90)	-140 (-96)
35	-100 (-73)	-105 (-76)	-115 (-82)	-120 (-85)	-130 (-90)	-135 (-93)	-145 (-98)
40	-100 (-73)	-110 (-79)	-115 (-82)	-125 (-87)	-130 (-90)	-140 (-96)	-150 (-101)

Winds above 40 MPH have little additional effect

☐ **LITTLE DANGER**

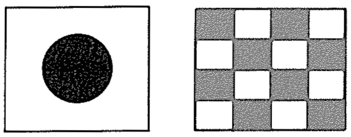
☐ **INCREASING DANGER (flesh may freeze within one minute)**

☐ **GREAT DANGER** (flesh may freeze within 20 seconds)

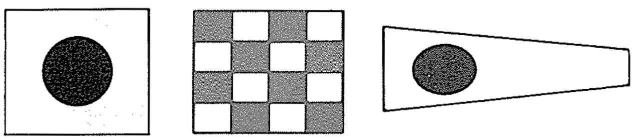
Figure 4-5 Equivalent Wind Chill Temperature Chart

WARNINGS

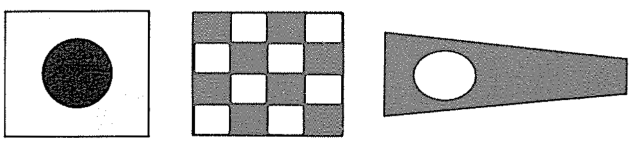
International Signal Code—All signals must be preceded by the "code" flag to signify that they are international signals.



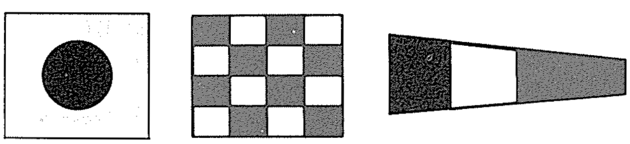
IN "I require a diver."



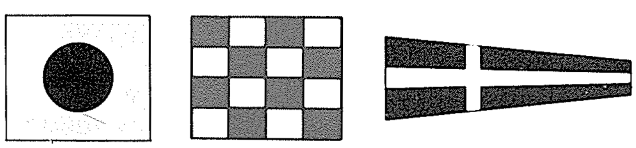
IN1 "I require a diver to clear my propeller."



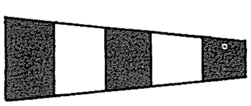
IN2 "I require a diver to examine bottom."



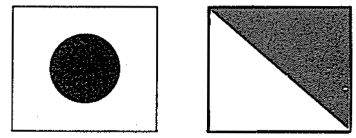
IN3 "I require a diver to place collision mat."



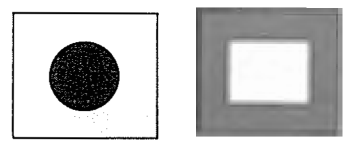
IN4 "I require a diver to clear by anchor."



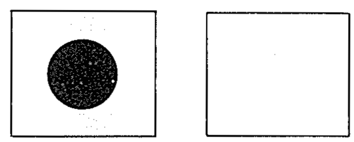
Code Flag



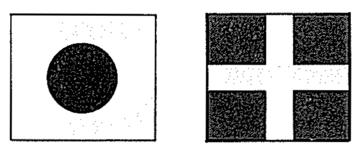
IO "I have no diver."



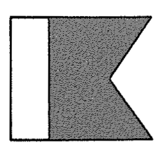
IP "A diver will be sent as soon as possible."



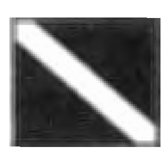
IQ "Diver has been attacked by diver's disease and requires decompression chamber treatment."



IR "I am engaged in submarine survey work. Keep clear of me and go slow."



A I have a diver down; keep well clear at slow speed.



Sport Diver

4-6 International Signal Codes

Since many diving operations are necessarily conducted in harbors, rivers and major shipping channels, the presence of other ships is often a serious problem. At times, it may even be necessary to close off an area or limit the movement of other ships. This should be taken into consideration during the planning effort and, if time permits, a local "Notice to Mariners" should be issued. At any time that diving operations are to be conducted in the vicinity of other ships, they should be properly notified by message or signal (Figure 4-6). If the operation will be carried on in the middle of an active fishing ground, the presence of small boats operated by people with varying levels of experience and competence must be anticipated. The diving team should assume that these operators are not acquainted with the meaning of any diving signals and take the necessary precautions to ensure that they remain clear of the area.

The degree of surface visibility is important. Reduced visibility may seriously hinder or force postponement of diving operations. For operations to be conducted in a known fog-belt, the diving schedule should allow for probable delays because of low visibility. The safety of the diver and support crew are the prime consideration in determining whether surface visibility is adequate or not. For example, a surfacing SCUBA diver might not be able to find his support craft, or the diver (and the craft itself) might be in danger of being run-down by surface traffic.

Other factors of location and surface conditions which may influence diving operations are territorial claims by other nations, the presence of foreign intelligence collection ships, and the potential of hostile action.

Underwater Conditions 4.2.2 Underwater conditions will have a major influence on the selection of divers, diving technique and the equipment to be used. Those conditions of particular concern are:

- Depth
- Type of bottom
- Tides and currents
- Visibility
- Temperature
- Pollution
- Obstacles or hazards

Depth is a major factor in the selection of both diving personnel and apparatus, and will influence the decompression profile for any dive. Operations in deep waters may also call for the use of special support equipment, such as underwater lights.

Depth must be carefully measured by two separate methods to insure accuracy. Also, the depth should not be measured at just one point but must be plotted for the general area of the operation. Soundings by a ship-mounted fathometer are reasonably accurate—but must be verified by either a lead-line sounding or through the use of a pneumofathometer (Figure 4-7). Depth readings on a chart are only to be taken as an indication of probable depth.

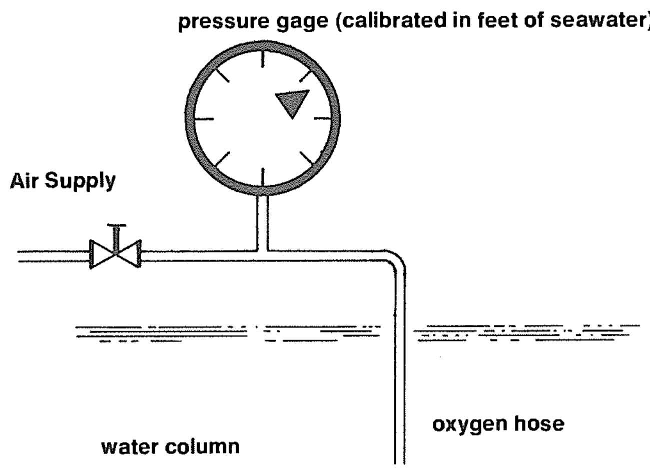


Figure 4-7 Pneumofathometer. It is attached to a diver or weighted object and lowered to the depth to be measured. Water is blown out of the hose with the air supply until a generally constant reading is noted on the pressure gage. The air supply is secured, and the actual depth (equal to the height of the water column displaced by the air) is read on the gage.

The type of bottom may have a decided effect upon a diver's ability to move and work both efficiently and safely. Advance knowledge of bottom conditions is important in the scheduling of work, in the selection of dive technique and equipment, and in anticipating possible hazards. The nature of the bottom is often noted on the chart for an area, but conditions can change within just a few feet. Independent verification of the type of bottom should be obtained by sample or observation. Figure 4-8 outlines the basic types of bottoms and the characteristics of each.

BOTTOM CONDITIONS

TYPE	CHARACTERISTICS	VISIBILITY	DIVER MOBILITY ON BOTTOM
Rock	Smooth or jagged, minimum sediment	Generally unrestricted by diver movement	Good, exercise care to prevent line snagging and falls from ledges.
Coral	Solid, invariably sharp and jagged, found in tropical waters only	Generally unrestricted by diver movement	As above
Gravel	Relatively smooth, granular base	Generally unrestricted by diver movement	Good, occasional sloping bottoms of loose gravel impair walking and cause falls
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 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	Common type of bottom, composed of varying amounts of silt and clay, commonly encountered in river and harbor areas	Poor to zero, work into the current to carry silt away from job site, minimize bottom disturbance, increased hazard presented by unseen wreckage, pilings and other obstacles	Poor, can readily cause diver entrapment, crawling may be required to prevent excessive penetration, fatiguing to diver

Figure 4-8 Bottom Conditions

Three basic types of currents affect diving operations:

- —River cr major ocean currents.
- —Current produced by the ebb and flow of the tides (which may add to or subtract from any existing current).
- —Undertow, or rip-current, caused by the rush of water returning from waves breaking along a shoreline.

The direction and velocity of normal river, ocean and tidal currents will vary with the time of the year, phase of the tide, configuration of the bottom, depth of the water and the weather. Tide and current tables show the conditions at the surface and should be used with caution in planning diving operations, since the direction and velocity of the current beneath the surface may be quite different. Usually there is much less current on the bottom than at the surface. Consequently, although the surface tidal current may be strong, bottom conditions may be well within the permissible range for diving.

Rip-currents will vary with the weather, the state of the tide and the slope of the bottom. These currents may run as fast as 2 knots and may extend as far as a half-mile from shore. They are not usually identified in published tables, and their location and force can vary significantly from day to day.

A diver wearing standard deep-sea gear, with a lifeline and heavy weights, can usually work in currents up to 1.5 knots without major difficulty. If supplied with an additional weighted belt, he should be able to accomplish useful work in currents as high as 2.5 knots. A SCUBA diver, who is essentially floating in the moving water, is severely handicapped by currents of greater than one knot. If planning an operation in an area of high current, it may be necessary to schedule work during periods of slack water, to minimize the tidal effect.

Underwater visibility varies with depth and with turbidity. Horizontal visibility is usually quite good in tropical waters, where a diver may be able to see more than 100 feet at a depth of 180 feet. Vertical visibility is almost always less than horizontal visibility. Visibility is usually poorest in harbor areas, because of large quantities of river silt, sewage and industrial wastes usually flowing into the harbor. Agitation of the bottom caused by strong currents and the passage of large ships is also a factor.

The degree of underwater visibility will influence selection of dive technique, and may greatly influence 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. A direct result could be an increase in bottom time, a longer period on station for the diving unit, and a requirement for additional divers on the team.

Water temperature can drastically affect a diver's performance as will be noted in Figure 4-9. In cold water, his ability to concentrate and his working efficiency will drop off rapidly. Even in water at moderate temperature (60°-70° F, 15.5°-21.5° C) body heat loss to the water can soon bring on excessive fatigue. In water above 86° F (30° C) the diver might suffer from overheating, causing exhaustion.

Usually, a diver may expect to work in waters that range in temperature from cool to very cold. Appropriate protective clothing is available to offset the effects of the cold and to minimize heat loss. However, in some parts of the world the normal water temperature is quite warm. Occasionally, a diver may be called upon to work in the vicinity of a sewer or industrial outfall discharging high temperature wastes. In such situations, he must be particularly alert for the possibility of exhaustion. To date, no practical diving apparatus or dress has been designed to protect the diver against unusually warm water.

Divers may encounter dangerous or unpleasant forms of pollution which can cause severe problems. A diver working near sewer outlets or industrial discharges may be exposed to the hazards of disease or chemical poisoning. Oil leaking from underwater wellheads or damaged fuel tanks can cause fouling of equipment and seriously impede a diver's movements. Toxic materials or volatile fuels leaking from barges or tanks can irritate the skin and corrode equipment. When using SCUBA, a diver may inadvertently take polluting materials into his mouth, posing both physiological and psychological problems. He is especially vulnerable to ear and skin infections.

In planning for operations in waters known to be polluted, full protective clothing and appropriate preventative medical procedures must be provided.

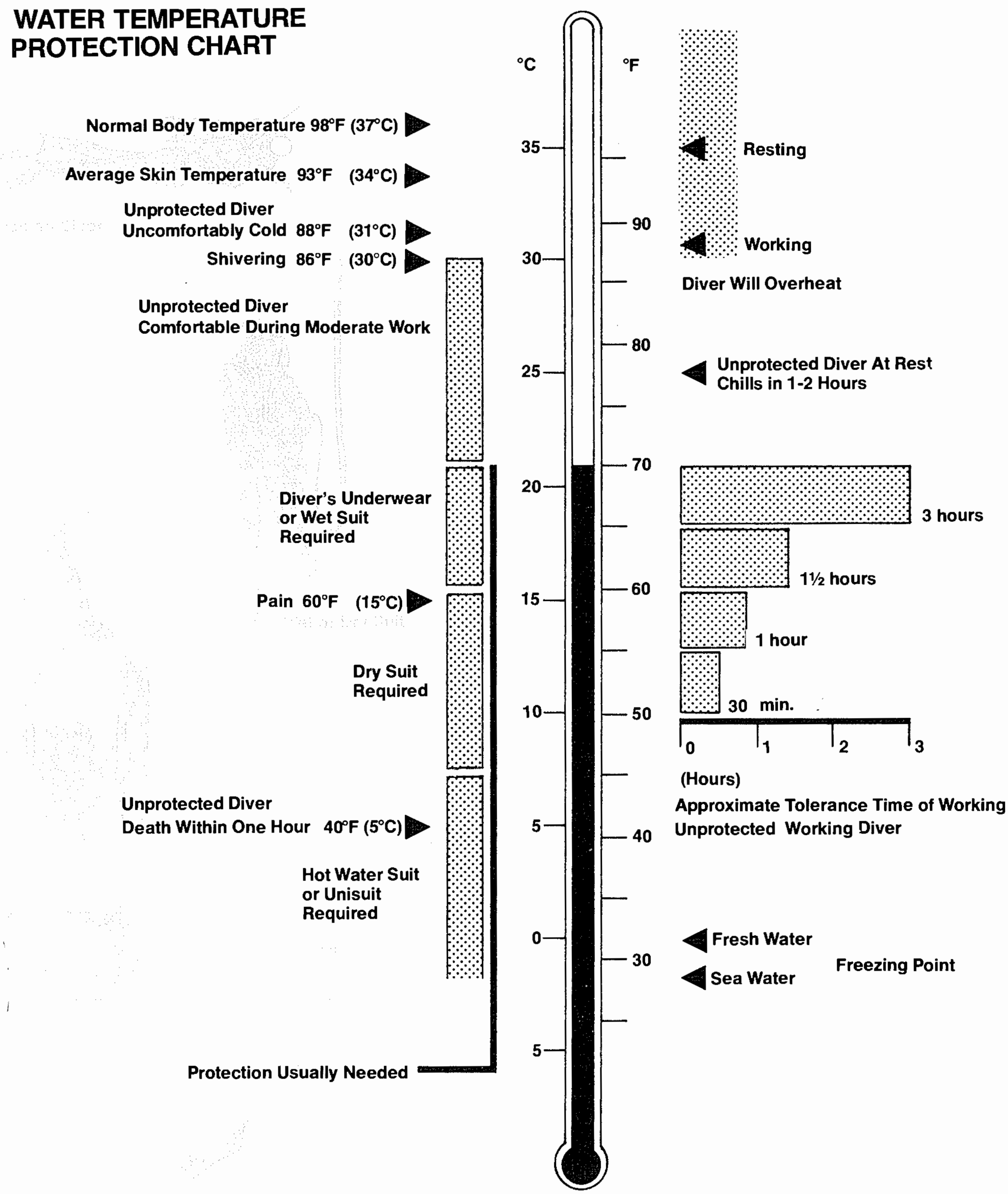


Figure 4-9 Water temperature protection chart

Various underwater obstacles, such as wrecks or discarded munitions, offer serious hazards to diving. Wrecks and "formal" dumping grounds are often noted on charts, but the actual presence of such obstacles might not be discovered until an operation begins. This is one of several reasons for scheduling a brief preliminary inspection dive, before a final work-schedule or detailed dive plan has been prepared. The surface and subsea conditions which affect diving operations are numerous. Reference to the Environmental Checklist, Figure 4-10, will help to ensure that no factors are overlooked in proper planning.

Resources 4.2.3 The manner in which an operation is planned and conducted will often depend upon variables not under the control of the diving team. In some operations, a time factor will take precedence over other considerations, while in other operations the availability (or non-availability) of equipment or personnel may be a vital factor. For any operation, the planning effort must identify resources known to be available, which include time, personnel, equipment, support or auxiliary equipment and supplies in order to:

- Insure the safety of all personnel
- Identify any shortages or inadequacies which should be remedied.
- Permit accomplishment of the operational objectives in a timely and effective manner.

Assistance and Emergencies 4.2.4 In the course of any diving operation, from the most routine to the most complex, three types of assistance may be required:

- Emergency assistance in the event of an accident or serious illness.
- Additional equipment, personnel, supplies or services.
- Guidance, authorization or decisions from higher command.

Unexpected developments or emergency situations usually are accompanied by a degree of confusion. The source and availability of any needed assistance, and the method for obtaining it as quickly as possible, must be determined in advance and be clearly understood by all members of the diving team as well as by other supporting personnel. The nearest activity having a recompression chamber must be identified—and notified—before the commencement of operations. The sources of emergency transportation, military or civilian, must be established and alerted, and the nearest diving medical officer should be located and notified. Additionally, arrangements must be made to insure a 24-hour availability for such emergency assistance.

Figure 4-11 is a suggested "Emergency Assistance Checklist" which, when fully filled in and posted at the diving station, will provide necessary information so that any member of the team could take prompt action.

ESTABLISH OPERATIONAL TASKS 4.3

With the objectives of the operation defined, and data gathered and studied to properly establish conditions under which diving will take place, a basic outline for the operation itself can be prepared. Each task should be identified, and placed in the context of an overall schedule, or job profile, so that the interrelationship of all tasks will be apparent. This should be done for even the most routine operations.

In developing a detailed task-by-task schedule for an operation, the following points should be kept in mind:

A. All phases of an operation are important. A common failure in planning is to put all of the emphasis on the actual dive phases, while not fully considering pre-dive and post-dive activities. Another common failure is to treat many operations—especially those of a recurring nature—with an indifference to safety that comes from over-familiarity.

B. The schedule should allocate sufficient time for preparation, transit to the site, rendezvous with other vessels or units, and establishment of a secure mooring.

C. Bottom time is always at a premium, and all factors which will in any manner affect bottom time must be carefully considered. These would include depth, decompression requirements, number of divers available, size of the support craft, and environmental conditions both on the surface and underwater.

Figure 4-12 illustrates the relationships between depth, bottom time, and total dive duration for non-repetitive dives.

D. The number and scope of repetitive dives which can be made by a diver in a given time period are limited as discussed in Chapter Seven.

E. It has been observed that the incidence of decompression sickness is reduced with increased diving frequency. If divers have been inactive and operating conditions permit, "work up" divers by initiating diving activity in the shallower part of the operating area and gradually progress to deeper depths.

F. Plan to work night and day, while weather permits, provided sufficient divers are available.

G. The use of different diving techniques will require different levels of personnel support. (See Table of Manning Levels, Figure 4-26).

H. The number of divers in the water at any one time should be kept to a minimum. The more divers underwater, working and/or decompressing, the greater the chance of an accident, and the heavier the burden on the support facility and crew.

I. In determining tasks, topside support personnel should not be overlooked—especially those who might not be considered "members" of the diving team. These might include boat operators, winch operators, or an anchor watch—each of whom may have a role to play in the operation, and each of whom must be properly selected and briefed.

J. Any schedule must be flexible, to accommodate unexpected complications, delays, and changing conditions.

A diving operation is not completed when the objective has been met, and good planning must carry the diving team through de-mounting the operation and the proper filing of all records and reports. In this connection, time should be allocated for:

- —Recovery, cleaning, inspection, repair and stowage of all equipment.
- —Disposition of any materials brought up during the operation.
- —De-briefing of divers and other team members.
- —Analysis of the success of the operation, as planned and as actually carried out.
- —Preparation and submission of all required reports (see Appendix B).
- —Re-stocking expended materials.
- —Insuring the readiness of the unit to respond to the next assignment.

ENVIRONMENTAL CHECKLIST

SURFACE

Atmosphere:
Visibility ____
Sunrise (set) ____
Moonrise (set) ____
Temperature (air) ____
Humidity ____
Barometer ____
Precip. ____
Cloud Descrip. ____
% Cover ____
Wind Direction ____
Force (knots) ____
Other: ____
____
____
____

Sea Surface:
Sea State ____
Wave Action:
Height ____
Length ____
Direction ____
Current:
Direction ____
Velocity ____
Type ____
Surf. Visibility ____
Surf. Wat. Temp. ____
Local Characteristics:
____
____
____

SUBSEA

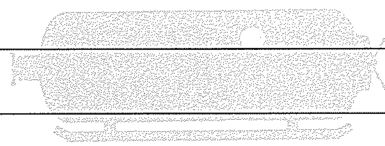
Underwater & Bottom:
Depth ____
Wat. Temp.
____ depth ____
____ depth ____
____ depth ____
____ bottom ____
Thermoclines ____
____
Current:
Direction ____
Source ____
Velocity ____
Pattern ____
Tides:
S High Water ____ time
S Low Water ____ time
Ebb dir. ____ vel. __
Flood dir. ____ vel. __

Visibility:
Underwater—
ft. ____ at ____ depth
ft. ____ at ____ depth
ft. ____ at ____ depth
Bottom:
ft. ____ at ____ depth
Bottom:
Type: ____
____
Obstructions: ____
____
____
____
Marine Life:
____
____
____
Other Data:
____
____

Figure 4-10 This environmental checklist is only a sample worksheet indicating data that might be gathered for an operation. Each planner should create a similar checklist to suit his particular operational situation.

EMERGENCY ASSISTANCE CHECKLIST

RECOMPRESSION CHAMBER

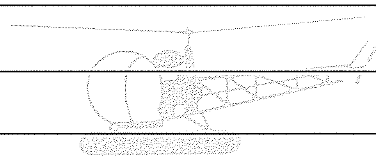


Location

Contact

Response Time

AIR TRANSPORTATION

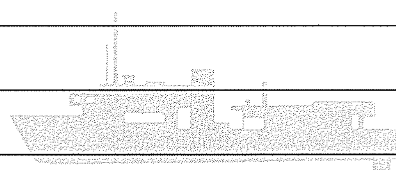


Location

Contact

Response Time

SEA TRANSPORTATION

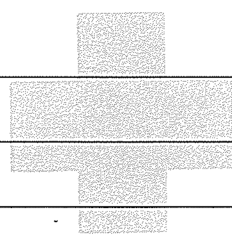


Location

Contact

Response Time

HOSPITAL

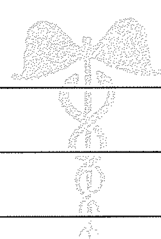


Location

Contact

Response Time

DIVING MEDICAL OFFICER

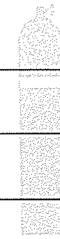


Location

Contact

Response Time

SUPPLIES

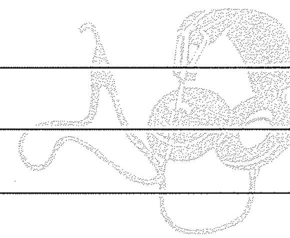


Location

Contact

Response Time

COMMUNICATIONS

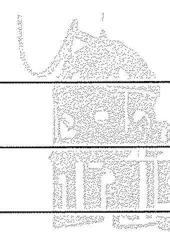


Location

Contact

Response Time

DIVING UNITS

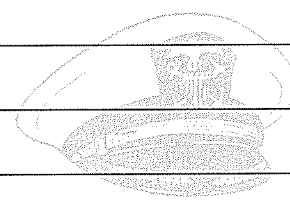


Location

Contact

Response Time

COMMAND



Location

Contact

Response Time

EDU Duty Phone Number (202) 433-2790

Figure 4-11 Emergency Assistance Checklist

TYPICAL TOTAL AIR DIVE DURATIONS

Depth (feet)	15	20	30	40	50	60	80	90	100	120	150	160	200	220	250	300
190	29 MIN (:29)	51 MIN (:51)	93 MIN (1:33)	143 MIN (2:23)												
180	27 MIN (:27)	46 MIN (:46)	83 MIN (1:23)	133 MIN (2:13)	178 MIN (2:58)											
170	25 MIN (:25)	42 MIN (:42)	76 MIN (1:16)	122 MIN (2:02)	160 MIN (2:40)	213 MIN (3:33)										
160	23 MIN (:23)	37 MIN (:37)	71 MIN (1:11)	112 MIN (1:52)	149 MIN (2:29)	193 MIN (3:13)										
150	21 MIN (:21)	32 MIN (:32)	65 MIN (1:05)	100 MIN (1:40)	139 MIN (2:19)	173 MIN (2:53)	254 MIN (4:14)									
140	19 MIN (:19)	28 MIN (:28)	58 MIN (:58)	86 MIN (1:26)	126 MIN (2:06)	157 MIN (2:37)	235 MIN (3:55)									
130	18 MIN (:18)	26 MIN (:26)	53 MIN (:53)	77 MIN (1:17)	113 MIN (1:53)	146 MIN (2:26)	211 MIN (3:31)									
120	NO DECOMP	24 MIN (:24)	46 MIN (:46)	72 MIN (1:12)	98 MIN (1:38)	131 MIN (2:11)	187 MIN (3:07)	222 MIN (3:42)	250 MIN (4:10)							
110	NO DECOMP	NO DECOMP	39 MIN (:39)	65 MIN (1:05)	86 MIN (1:26)	116 MIN (1:56)	169 MIN (2:49)	198 MIN (3:18)	226 MIN (3:46)							
100	NO DECOMP	NO DECOMP	35 MIN (:35)	57 MIN (:57)	78 MIN (1:18)	99 MIN (1:39)	153 MIN (2:33)	175 MIN (2:55)	198 MIN (3:18)	253 MIN (4:13)						
90	NO DECOMP	NO DECOMP	NO DECOMP	49 MIN (:49)	70 MIN (1:10)	87 MIN (1:27)	135 MIN (2:15)	158 MIN (2:38)	177 MIN (2:57)	222 MIN (3:42)						
80	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	61 MIN (1:01)	78 MIN (1:18)	114 MIN (1:54)	137 MIN (2:17)	158 MIN (2:38)	194 MIN (3:14)	260 MIN (4:20)					
70	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	69 MIN (1:09)	99 MIN (1:39)	114 MIN (1:54)	134 MIN (2:14)	172 MIN (2:52)	221 MIN (3:41)	246 MIN (4:06)				
60	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	88 MIN (1:28)	105 MIN (1:45)	115 MIN (1:55)	147 MIN (2:27)	199 MIN (3:19)	209 MIN (3:29)	271 MIN (4:31)			
50	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	126 MIN (2:06)	172 MIN (2:52)	182 MIN (3:02)	236 MIN (3:56)	261 MIN (4:21)		
40	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	NO DECOMP	232 MIN (3:52)	262 MIN (4:22)	320 MIN (5:20)

Bottom Time (minutes)

Figure 4-12 Typical Total Air Dive Durations

SELECT DIVING TECHNIQUE 4.4

There are three basic types of diving equipment in current use for U. S. Navy air diving operations, and for certain operations, one or another of these three might be more suitable. In other operations, there may be no clear-cut choice, and the selection of diving technique may depend upon availability of equipment or trained personnel. These techniques are:

- Open-circuit SCUBA.
- Surface-supplied lightweight gear.
- Surface-supplied deep-sea (heavy) gear.

NOTE:
Oxygen, mixed gas and saturation diving techniques are discussed in Volume II of this manual.

The general characteristics of each type are described in Figures 4-13 through 4-15. The following comparison of SCUBA and surface-supplied techniques highlights the significant differences between the methods, as well as indicates the influence these differences will have on planning.

Comparison of SCUBA and Surface-Supplied Diving 4.4.1 A close look at the advantages and disadvantages of SCUBA will best emphasize the basic factors by which it may be compared with surface-supplied gear. The main advantages are mobility, depth flexibility and control, portability, and reduced requirement for surface support. The main disadvantages are limited depth, limited duration, increased breathing resistance, lack of voice communications (although recent developments are dealing with this problem), limited environmental protection, remoteness from surface assistance, and those negative psychological and physiological problems which may arise from isolation and direct exposure to the underwater environment.

The SCUBA diver is not hindered by bulky or heavy equipment. He can cover a considerable distance and can have an even greater range through the use of auxiliary propulsion. He does not have to be tethered to the surface, and can move freely in any direction.

SCUBA equipment is designed to have a nearly neutral buoyancy when in use, permitting the diver to change or maintain depth with ease. This gives the SCUBA diver a particular advantage since he can work at any level in the water column. A surface-supplied diver using heavyweight gear would need rigging or staging.

The portability and ease with which SCUBA can be employed is a distinct advantage. SCUBA equipment can be transported by almost any means and can be put into operation with minimum delay. Within its operational limitations, SCUBA offers a flexible and economical method for accomplishing a wide range of tasks.

The operational limitations must, however, be considered. The SCUBA diver must remain within the limits of the No-Decompression Table shown on page 7-16, except in an emergency. His bottom time is also limited by the fixed air supply of his SCUBA. The deeper a SCUBA diver operates, or the harder he works, the greater will be his consumption of air. A SCUBA with a surface endurance of better than 2 hours will only provide 35 minutes duration at 99 feet. If any decompression time is involved, it must also be supported by this same air supply unless extra bottles have been provided at the decompression stops.

Dead space in the SCUBA and resistance caused by the regulator and the exhaust valve make breathing an effort. The diver must expend energy just to breathe, thereby limiting the amount of work he can accomplish. However, in practice, this breathing resistance energy loss does not compare to the energy expended in moving across the bottom in surface-supplied heavyweight gear.

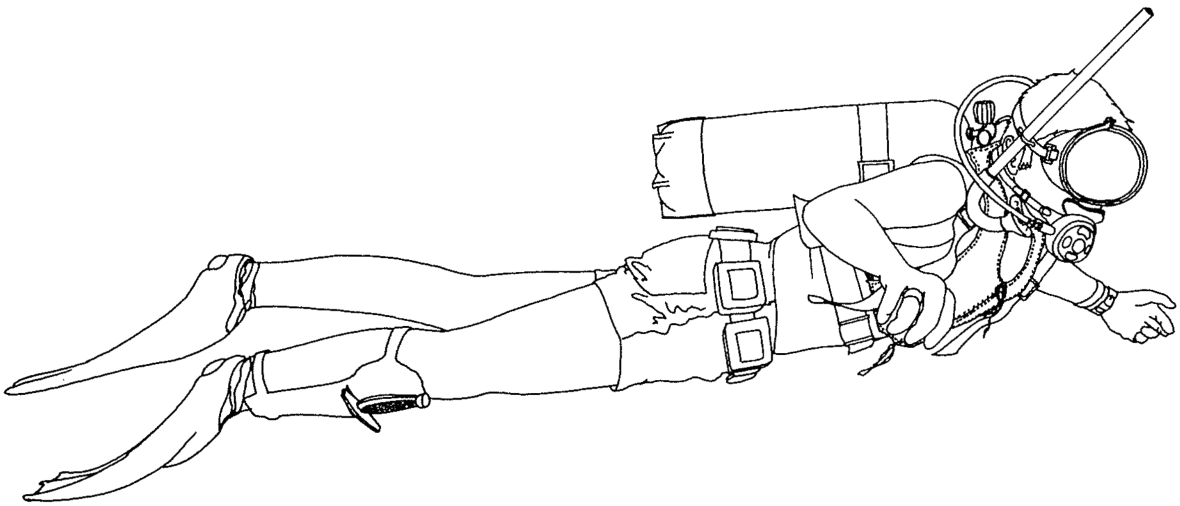
The SCUBA diver, more directly exposed to the underwater environment than a diver in surface-supplied gear, is not as well protected from cold or from contact with marine plants and animals. He is easily swept along by current. Even when accompanied by a buddy, the SCUBA diver usually swims in virtual isolation, without surface contact and without surface communications. These factors coupled with the knowledge that he is entirely dependent upon his apparatus and its limited air supply, places an increased mental burden upon the diver.

Surface-supplied lightweight gear allows the diver almost as much mobility, within limits, as with SCUBA. It provides unrestricted breathing, and it offers ther-

SCUBA

GENERAL CHARACTERISTICS

Figure 4-13



Minimum Equipment—
Open-circuit SCUBA
Life preserver
Weight belt
Knife
Face mask
Swim fins

Principle Applications—
Shallow water search
Inspection
Light repair and recovery
Clandestine operations

Advantages—
Rapid deployment
Portability
Minimum support
Excellent horizontal and vertical mobility
Minimum bottom disturbances

Disadvantages—
Limited endurance (depth and duration)
Breathing resistance
Limited physical protection
Influenced by current
Lack of voice communication

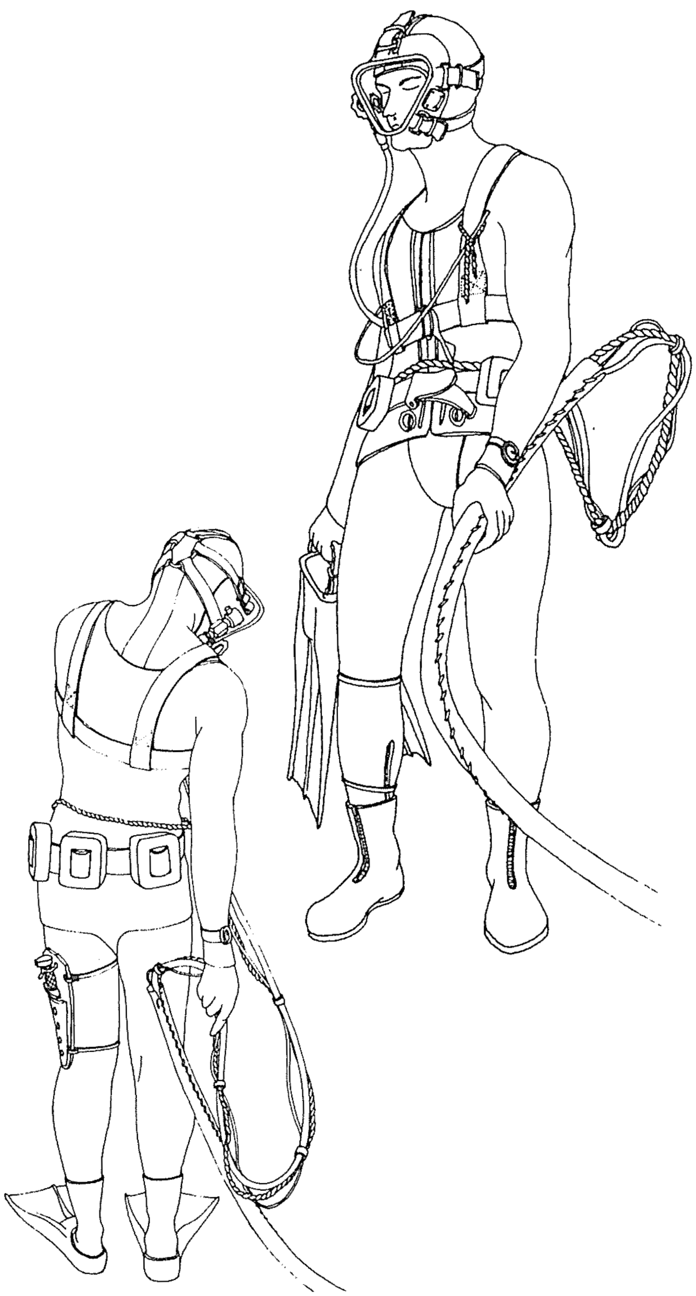
Restrictions—
Working limits—
Normal 60 feet/60 minutes
Maximum 130 feet/10 minutes
Current—1 knot maximum
Diving team—minimum 4 men

Operational Considerations—
Buddy and standby diver required
Small boat required for diver recovery
Avoid use in areas of coral and jagged rock
Moderate to good visibility preferred

LIGHTWEIGHT DIVING

GENERAL CHARACTERISTICS

Figure 4-14



Minimum Equipment—
Diver's Mask USN MK 1 or Jack Browne mask
Wet suit
Weight belt
Knife
Swimfins or shoes
Surface umbilical

Principle Applications—
Shallow water search
Inspection and major ship repair
Light salvage

Advantages—
Unlimited by air supply
Good horizontal mobility
Voice and/or line pull communications
Fast deployment

Disadvantages—
Limited physical protection
Limited vertical mobility
Large support craft required

Restrictions—
Work limits—Jack Browne —
Normal 60 feet/60 minutes
Maximum 90 feet/30 minutes
Work limit—MK 1 without open bell
Maximum 130 feet/10 minutes
Work limit—MK 1 with open bell
Maximum 190 feet/60 minutes
Current—2.5 knots max.
Diving team—minimum 5 men

Operational Considerations—
Ability to free ascend to surface required
Adequate air supply system
Standby diver required

DEEP-SEA DIVING GENERAL CHARACTERISTICS

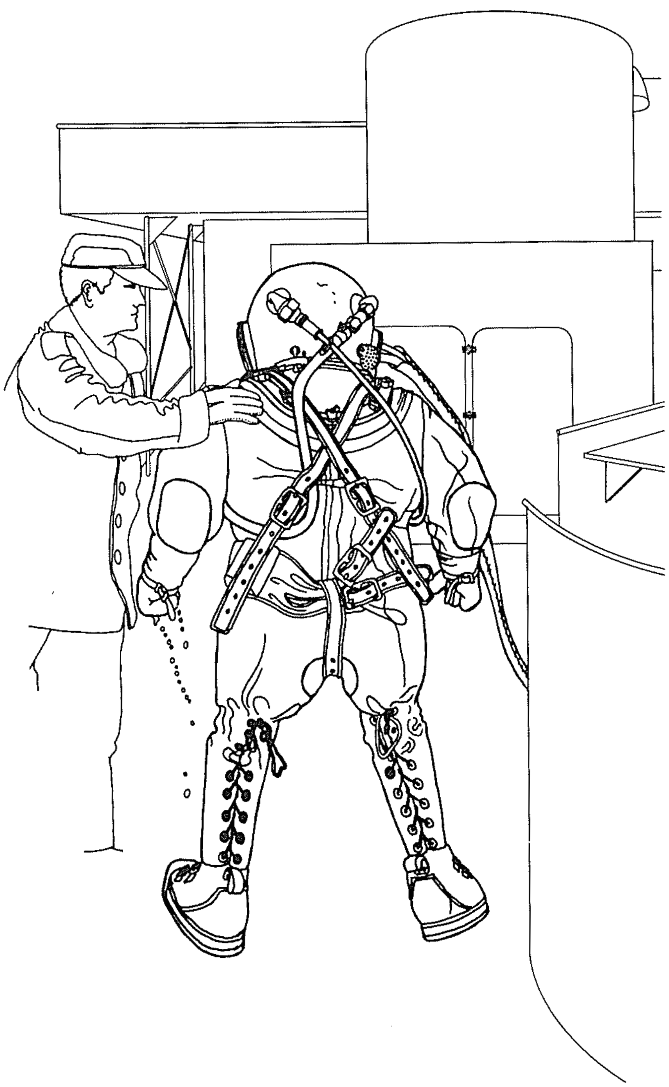


Figure 4-15

Principle Applications—
Deep diving operations
Heavy salvage and repair
Underwater construction

Advantages—
Unlimited by air supply
Maximum physical and thermal protection
Voice and line pull communication
Variable buoyancy

Disadvantages—
Slow deployment
Poor mobility
Large support craft and surface crew

Restrictions—
Work limits—
Normal 190 feet/40 minutes
Maximum 250 feet/90 minutes (Exceptional Exposure)
Current—2.5 knots
Diving team—minimum 6 men

Minimum Equipment—
Helmet and breastplate
Diving dress
Thermal underwear
Weight belt
Weighted shoes
Knife
Rubber cuffs and/or gloves
Surface umbilical

Operational—Considerations—
Adequate air supply system
Stand-by diver required
Medical officer and recompression chamber required below 170 feet
Exceptional exposures require approval of Commanding Officer or higher authority.

mal and environmental protection superior to any equipment worn by the SCUBA diver. The lightweight diver, as the SCUBA diver, is restricted under normal conditions to the limits of the No-Decompression Table.

Lack of voice communications in the Jack Browne mask is a significant limitation in applications requiring extensive coordination with topside support. Use of the new Diver's Mask USN MK 1 eliminates this shortcoming.

The lack of excess weight, required by the deep-sea technique to overcome the additional buoyancy of an inflated suit, permits the lightweight gear-equipped diver to move freely in the water column. This characteristic, coupled with the minimum tending support required, makes the use of lightweight gear a logical choice for shallow water ship repairs, inspections, searching and clearing lines. The gear is generally restricted to use at 60 feet and shallower depths where direct ascent to the surface is possible in the event of a loss of the facemask. One exception to this rule is that the lightweight outfit may be used to work inside submarine tanks.

The heavyweight (deep-sea) gear is intended primarily for bottom-oriented, arduous work. It offers the diver maximum thermal and physical protection from the environment and obstacles. The helmet affords the advantages of head protection in areas of overhead obstructions, minimum breathing resistance, two-way voice communications, and an air reserve in emergency situations.

The controlled buoyancy associated with the inflatable dress makes it a desirable technique in working in muddy bottoms and in conducting jetting, tunneling or other work where the reaction forces of tools are high. Since the diver's negative buoyancy is easily controlled, the deep-sea rig allows the conduct of diving in high current areas. The overall protection, comfort, and duration afforded to the diver allows the use of the deep-sea rig to the maximum depth limits of air diving.

The primary working drawbacks of using heavyweight gear lie in its cumbersome characteristics which restrict bottom movement and a general lack of freedom in working in the vertical range of the water column. Dressing time, weight of the gear, and additional tending personnel required also tend to restrict ready deployment.

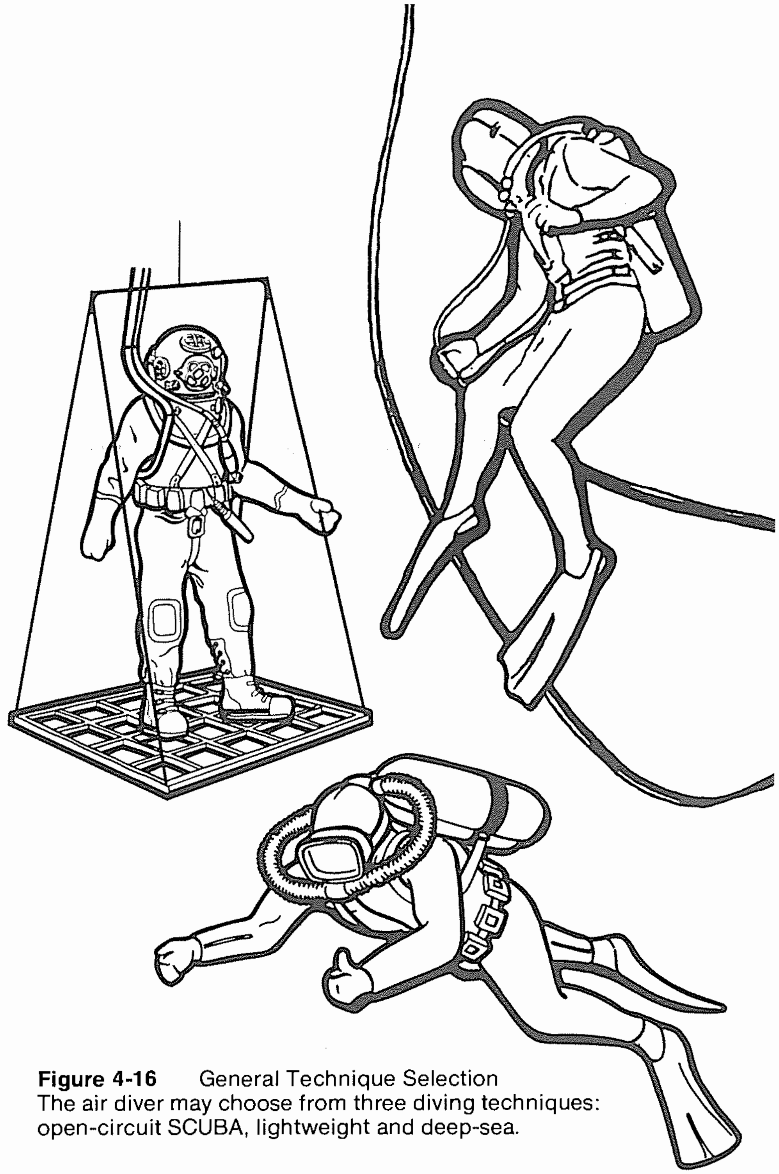


Figure 4-16 General Technique Selection
The air diver may choose from three diving techniques: open-circuit SCUBA, lightweight and deep-sea.

Choice of Technique 4.4.2 The first two factors to be considered in selecting the basic technique to be used for a given dive, are **duration** and the **depth** of the dive. A dive of extended length even in shallow water may require an air supply in excess of that which could be provided by SCUBA. Specific limits for depth have been established for each type of diving gear. These are presented in Figure 4-17, and may not be exceeded without specific approval of the Diving Officer or Commanding Officer, and only then when overriding operational considerations are involved.

Any SCUBA dive which will require decompression should be avoided, although this is not always possible. For any technique, and for any duration a diver may not dive beyond the depth for which he has been qualified.

DEPTH LIMITS FOR AIR DIVING

DEPTH F.S.W.(Meters)	(1, 6) LIMIT FOR	NOTES
35 (10.7)	Nondesignated diver in an emergency situation.	(2)
60 (18.3)	Open-circuit scuba and lightweight diving equipment with standard mask; normal working limit.	(2)
90 (27.4)	Lightweight diving equipment with standard mask; maximum working limit.	(2)
130 (39.6)	Open-circuit scuba; maximum working limit.	(2)
130 (39.6)	Lightweight diving equipment with Diver's Mask USN Mk1; maximum working limit without roving bell.	(2)
170 (51.8)	Diving without a medical officer and a recompression chamber at the scene.	(3)
190 (57.9)	Lightweight diving equipment with Diver's Mask USN Mk1; maximum working limit with roving bell.	(3, 4)
190 (57.9)	All divers except those qualified for mixed-gas diving.	
190 (57.9)	Surface-supplied deep-sea (air) diving equipment; normal working limit.	(3, 4)
250 (76.2)	Surface-supplied deep-sea (air) diving equipment; maximum working limit: exceptional exposure.	(3, 5)

Notes:

(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 officer in charge of the diving operation or from higher authority.

(2) Under normal circumstances, do not exceed the limits of the No-Decompression Table. Dives requiring decompression may be made if considered necessary by the officer in charge of the diving operation. The total time of a SCUBA dive (including decompression) must never exceed the duration of the apparatus in use, disregarding any reserves.

(3) A diving medical officer and a recompression chamber are required on the scene for all dives deeper than 170 feet.

(4) Exceptional exposure dives are not permitted. Exceptional exposure dives, printed in RED in the Standard Air Decompression Table, are computed for emergency situations only. Such situations defy complete assurance of safety, even if the correct decompression schedule is used.

(5) Do not exceed the limits of the Standard Air Decompression Table for exceptional exposures.

(6) For depth ranges and diving techniques not covered in the table refer to Vol. II *Mixed Gas Diving*.

Figure 4-17 Depth limits for air diving.

SELECT EQUIPMENT AND SUPPLIES 4.5

Equipment procured for use in the U.S. Navy has been tested under stringent laboratory and field conditions to insure that it will perform according to design specifications under the most difficult conditions that might be encountered. Diving teams will not use any apparatus which has not been accepted and approved for Navy use, unless such use is itself part of an authorized testing program. Additionally, unauthorized modifications are not permitted, no matter how logical they might seem at the time.

A list of all approved diving equipment is contained in Appendix D, which should be consulted whenever there might be a doubt as to the acceptability of a particular piece of gear. As noted on the list, the selection of some items of equipment is left to the choice of the diver, and may be procured from commercial or Navy sources.

An important item of supply is the air used by the divers for breathing. All such air supplies, whether provided to the diver in tanks or through a compressor taking suction from the atmosphere, must meet four basic criteria:

- The air must conform to established standards of purity.
- An adequate volume must be available.
- The flow to the diver must be sufficient.
- A back-up supply must be available for surface-supplied diving.

The standards for purity of the air supplied for breathing have been established by the Bureau of Medicine and Surgery, and are outlined in Chapter Five. Compressors which are used for charging SCUBA bottles, for filling air banks on board ship or for supplying air directly to divers, must also meet certain specifications and must be specifically designated for use in diving operations. Such compressors are equipped with filters for removing contaminants from the air; when in use, they should be carefully positioned to prevent contamination of the air from compressor engine exhaust or from stack gas or other shipboard exhaust.

Surface-supplied diving requires a heavy-duty, high volume, low pressure compressor system which is usually permanently installed in the support ship or craft. A back-up system might be a portable compressor and/or a bank of high-pressure air cylinders fitted with an appropriate reducing valve. Basic requirements for air compressors and cylinders used in air-supply systems are discussed in Chapter Six.

Air for SCUBA operations is provided in individual tanks which are carried by the divers. These tanks are filled from a bank of high-pressure cylinders or with a small high-pressure compressor (although this is a much slower method). The techniques for filling SCUBA tanks are described in Chapter Five.

A particular item of equipment, not carried on any "approved" list but vital for many diving operations, is a diving support craft. Any craft used for diving operations, regardless of the technique being supported, must have seven basic characteristics:

A. It must be seaworthy, both in design and condition.

B. It must be equipped with required lifesaving and other safety gear.

C. It must be in good repair, with a reliable engine (unless the craft is a moored float or barge).

D. It must have ample room for the divers to dress and rest.

E. It must provide adequate shelter and working area for the support crew.

F. It must be able to safely carry all equipment required for the operation.

G. It must be properly manned by a well-trained crew.

SCUBA operations are normally best conducted from a small boat. This can range from an inflatable rubber raft with an outboard engine (Figure 4-18), to a motor whale boat, to a small landing craft. These boats are normally standard fleet types, and there is usually no need for special or extensive modifications. In planning for SCUBA diving, the availability of an appropriate small boat will be a factor to be considered for the safety of the divers. Even if the divers will be operating from a large ship or diving float, a small boat must be standing by, ready to respond as a rescue boat in the event a surfacing diver is in

SURFACE SUPPLIED DIVING BOAT REQUIREMENTS

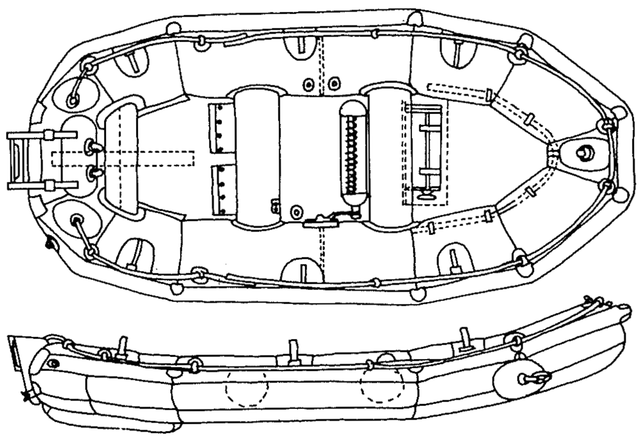


Figure 4-18 SCUBA Diving Boat—Illustrated is the seven-man inflatable boat normally employed in UDT operations. Its design includes all the required features of a SCUBA boat; mobility, ease of entry to and from the water, stability and adequate space.

Figure 4-19 LCM diving boat.

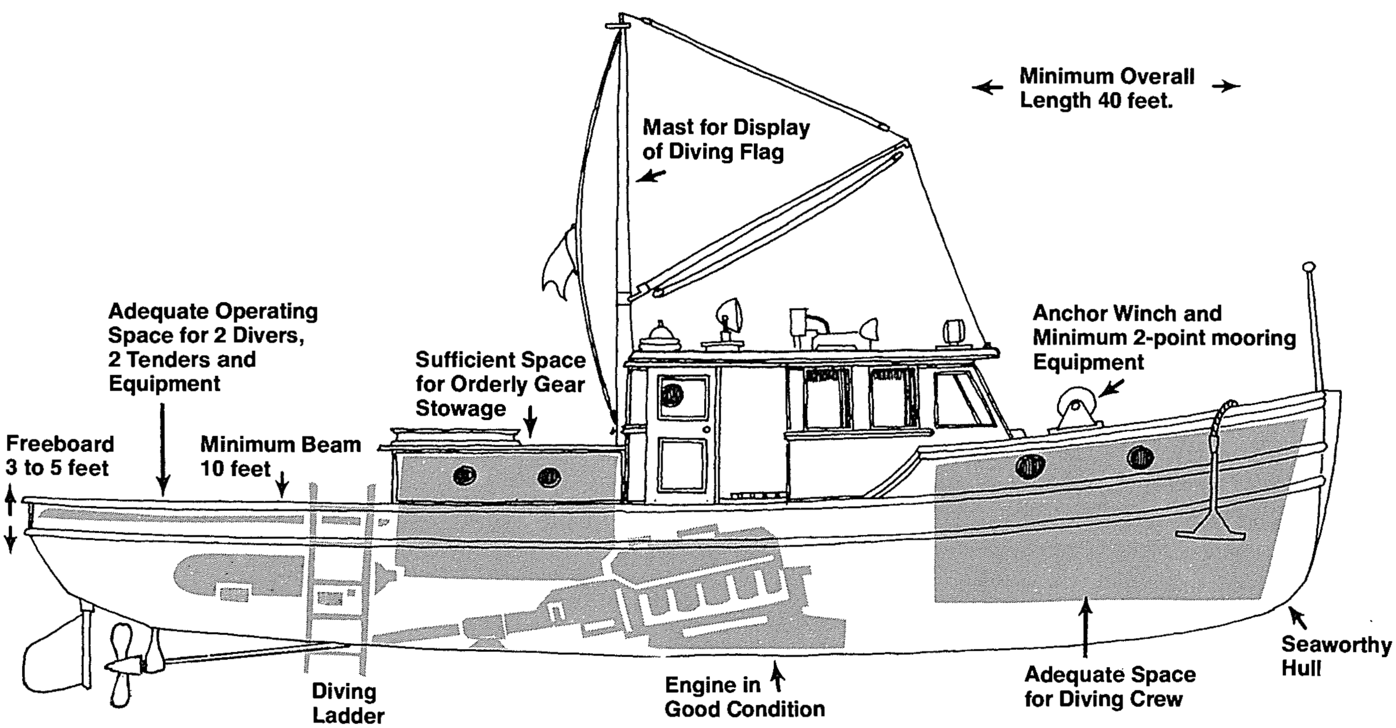


Figure 4-20 General Requirements of a Surface-Supplied Diving Boat.

trouble at some distance from the support site. In this same regard, a boat used by SCUBA divers must be able to quickly slip any moorings and move to a diver needing assistance.

A craft intended to support surface-supplied diving operations must be fairly substantial, and will usually be specifically modified for the purpose. Many naval small craft can easily be converted for such use. Figure 4-19 illustrates a typical conversion and Figure 4-20 points out essential characteristics of both the basic boat and the modifications. Figure 4-21 is a checklist of equipment which should be carried on board, and Figure 4-22 is a safety check-list for any diving boat operation.

At times, other support equipment may be needed in a given operation. This could include barges, tugs, floating cranes, vessels or aircraft for area search, and so forth. The need for such additional equipment should be anticipated as far in advance as possible.

Diving Boat Equipment Checklist

ALWAYS REQUIRED

Anchor Gear & Spare
Binoculars
Blankets
Boat Hook
Boat Operations Checklist
Bucket & Soap
Bumpers, Boat
Call Signs, Mother Ship or Station
Charts
Compass
Decompression Tables
Descending/Decompression Line
Diving Equipment
Diving Handbook
Drinking Water
Fire Extinguishers
First Aid Equipment
Flares
Flashlights
Fuel; Engine & Compressors
Gloves
Heaving Line
Knives
Lead-Line (or Pneumofathometer)
Lifesaving Gear (Standard)
Lights; Navigation, Surface, Underwater
Line, Working, ¼″ Manila
Logs, Diving
Mooring Lines
Oil; Engine, Compressor
Pencils
Radio
Signals; Sound, Day-Shapes, Flags
Tide Tables
Timepiece
Tools; Hand, Engine, Compressor, Air Bank

OPTIONAL

Blue Print or Sketch of Job
Boat Stowage Box
Bull Horn
Buoys; Mooring, Marker
Come-Along
Ear Ease
Food
Foul Weather Gear
Grease
Grease Pencils
Insect Repellant
Lift Bags
Luff Tackle
Matches
Markers, Waterproof
Pressure Gage
Probe, 10′ Pipe (1 inch dia.)
Radar Reflector
Sea Sickness Pills
Shackles, Snap Hooks
Slate, Underwater
Stadimeter
Sun Shades
Sun Tan Lotion
Tank Rack, SCUBA
Tape, Electrical & Masking
Tape Measure (6′)
Tarpaulines
Thermometer, Underwater
Tow Line
Towels
Wire and Fasteners
Whistles, Mouth

Figure 4-21

DIVING BOAT SAFETY CHECKLIST

All personnel involved in the operation of diving boats, launches, barges, floats, and other types of secondary small craft should be briefed and must understand the following safety precautions.

1. **Inspect** the specified boat or craft and determine its suitability for the intended mission and operating environment. Ensure that:
   ________ Boat (craft) is sound, seaworthy, and well found.
   ________ Power plant is running well and fully tested.
   ________ Required safety and running equipment is on board and in workable condition.
   ________ Proper gear for diving operation is on board and operational (see "Optional & Always" Onboard Checklist).
   ________ The assigned boat crew is fully qualified to operate that particular craft.
2. **Know** the details of the Emergency Assistance Checklist. Make sure it is completely filled out for small craft operations, with a legible copy placed on board.
3. **Inspect** all communications gear, radios, CB units, underwater communications, power sources, walkie-talkies, and ensure that they have been fully tested and are operational.
4. **Determine** that all non-powered communication equipment (flags, sound signals, flares, radar reflectors, etc.) are on board, are complete, and are operational.
5. **Know** all pre-determined signals, proper call-signs, etc.
6. **Know** all routine and emergency signals (for divers):
   ________ Sound (whistle, horn, recall) ________
   ________ Sight (Hand signals from diver)
   Pick me up   Pick me up now!
   Hold Everything
   OK   Up   Down
   ________ Signals (Lights) ________________
   (Day Shapes) ______________
   (Flags) ________________
7. **Determine** that adequate and safe mooring equipment is on board, and personnel are familiar with proper mooring techniques.
8. **Know** who is in charge of the boat and responsible for the giving of orders to "Stop" and "Start" the small craft. Orders to commence boat operations that affect divers are given **only** by the Diving Supervisor.
9. **Before getting Underway,** check with the Diving Supervisor for:
   ________ An "all-aboard" head-count.
   ________ His approval that all diving equipment, lines, safety equipment, etc. are on board.
10. **Plan for various Boat Handling** during Diving Operations to include:
    ________ Dropping off of divers
    ________ Picking up divers
    ________ Towing divers
    ________ Getting underway in an emergency
    ________ Positioning boat in a
    2 point moor   4 point moor
    ________ Handling of divers' lines during descent, ascent, hanging-off, raising or lowering tools and gear, drop-off and pick-up.
    ________ Setting/retrieving of buoy markers
    ________ Moving or towing of platforms, rafts, rubber boats, search sleds, etc.
11. **Ensure that stowage** of diving supplies and gear does not block access to:
    ___ Fire extinguishers   ___ Boat hook
    ___ Life preservers   ___ Heaving line
    ___ Ground tackle   ___ Emergency lights
    ___ Engine spaces   ___ Flares
    ___ Communication gear   ___ First Aid kit
    ___ Bilge pump or switch ___ Diving platform

12 **Know these general safety precautions** that apply to Boat Operations.
   ________ **Place** all intakes for the diving air compressor **upwind** of engine or auxiliary power plant exhausts.
   ________ **Ensure** safety of the boat when:
   ________ Handling gasoline, explosives or other dangerous material.
   ________ Shoring and handling of heavy equipment.
   ________ Securing gear for heavy weather.
   ________ Cutting, welding, and other operations involving fire.
   ________ **When** divers are down . . .
   ________ Do not change a moor
   ________ Do not set anchors
   ________ Do not drop heavy items overboard
   ________ And . . . NEVER START ENGINES WHEN DIVERS ARE DOWN OR ALONGSIDE.

Figure 4-22 Diving Boat Safety Checklist

SELECT AND ASSEMBLE THE DIVING TEAM 4.6

When planning diving assignments, and matching the qualifications and experience of diving personnel to specific requirements of the operation, a thorough knowledge of the duties, responsibilities and relationships of the various members of the diving team is essential.

The ultimate responsibility for the safe and effective conduct of all diving operations rests with the Commanding Officer. His responsibilities are defined and his authority is confirmed by the provisions of U.S. Navy Regulations and such other fleet, force or type command regulations as may from time to time be issued. In order that diving operations may be efficiently conducted, the Commanding Officer delegates appropriate authority to selected members of his command, who with subordinate personnel, make up the diving team. These are the Diving Officer, the Diving Supervisor, divers qualified in various techniques and equipment, support personnel such as tenders (who should be qualified divers if possible), timekeepers, and medical personnel as indicated by the type of operation (Fig. 4-23, 4-24). Other members of the ship's company, properly instructed, will provide support in varying degree in such roles as boat crew, winch operators, and line handlers.

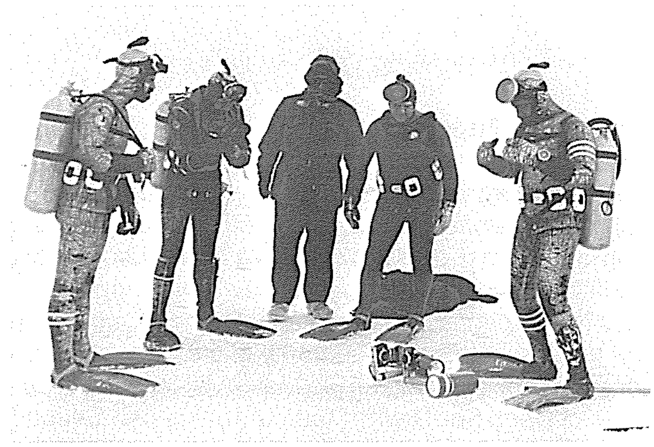


Figure 4-23 A SCUBA diving team, including a Diving Supervisor, two divers, one standby diver, one tender and a timekeeper, completes their pre-dive duties.

Figure 4-24 A deep-sea dive to 150 feet, requiring the work of one diver, gets underway. The team consists of a Diving Supervisor, the diver, a standby diver, two tenders and a timekeeper.

The Diving Officer 4.6.1 The Diving Officer is in charge of all diving operations and training undertaken by the command, and responsible for the qualifications and safe diving practices of all divers assigned. He should, whenever possible, be a qualified diver. However, any officer may be assigned as a Diving Officer. It is his own responsibility in such a case to become thoroughly familiar with basic diving technique and have a detailed knowledge of all applicable regulations. The Diving Officer must ensure that equipment is in good repair, well maintained and correctly stowed, and that any authorized modifications have been carried out by properly trained personnel (whether on board or at a higher level maintenance facility).

The Diving Officer is responsible for the preparation of basic plans for all diving operations, subject to final approval by the Commanding Officer. He coordinates his activities with other shipboard departments and with any other diving units which may be involved. He ensures that all personnel participating in the conduct of a diving mission are thoroughly briefed on the mission, and that they know and understand all applicable safety regulations and emergency procedures. Further, it is his responsibility to establish a vigorous and continuing training program for his unit including frequent drill in emergency procedures as well as practice in routine and non-routine operations. He should see that every opportunity for cross-training is used to full advantage. And, finally but most importantly, he has a primary responsibility for the safe conduct of all diving operations within the command.

The Diving Supervisor 4.6.2 The man in charge of the actual diving operation is the Diving Supervisor, and no diving operations may be conducted without his presence. He may be an officer or an enlisted man depending on the size of the operation and the availability of qualified personnel. When appointing a Diving Supervisor from the enlisted ranks, selection will be based upon the seniority of the available personnel in the following order: Master Diver, First Class Diver or Deep Sea Diving Medical Technician, Second Class Diver. Regardless of rank, he must himself be a qualified diver of demonstrated abilities and experience in whom the Commanding Officer has full confidence.

The Diving Supervisor assists the Diving Officer in preparing for an operation, and, based upon his own training and experience, plots the operation step-by-step. He must consider all possible contingencies, determine equipment requirements, recommend diving assignments, and establish back-up requirements for the operation. The Diving Supervisor should be familiar with all men on the team and be able to evaluate the qualifications and physical fitness of the divers selected for a particular job. The Diving Supervisor inspects all equipment to be used and conducts pre-dive briefings of personnel. When the operation begins, he is in charge of all diving on the scene. While the operation is underway, the Diving Supervisor monitors progress, de-briefs divers returning to the surface, updates instructions to working divers, and ensures that the Diving Officer, Commanding Officer and other personnel as necessary are advised of progress and of any changes to the original plan.

When the mission has been completed, the Diving Supervisor is responsible for gathering appropriate data, for analyzing the results of the mission, and for preparing reports for submission to higher authority. He will also make sure that any required records are completed. These may range from equipment logs to individual diving records.

Diving Personnel 4.6.3 The diver must be qualified for the diving technique used, the particular equipment involved, and for diving to the depth required. While working, he must keep topside personnel informed of conditions on the bottom, of his progress, and of any developing problems which may indicate the need for changes to the plan or a call for assistance from other divers. To insure his personal safety he must always obey a signal to surface. If using SCUBA, he must keep track of his own bottom time.

The diver is responsible for the diving gear he will use and must be sure that it is complete, in good repair, and ready for use at any time.

Navy divers must be qualified and designated in accordance with instructions issued by the Bureau of Naval Personnel (BUPERS). A general abstract of the requirements for diving qualification is contained in Appendix E.

A standby diver is a mandatory requirement for all diving operations.

The standby diver is a fully qualified diver, assigned for back-up or to provide emergency assistance, and immediately ready to enter the water. For surface-supplied operations, the standby diver must be completely dressed, including his weighted belt and breastplate. Under certain conditions, the helmet should also be worn. A standby SCUBA diver should wear the apparatus and be completely ready for quick deployment. The standby diver receives the same briefings and instructions as the working diver, and monitors the progress of the work as reported by the diver on the bottom so that if called upon for assistance, he is fully prepared to respond.

A buddy diver is the diving partner for a SCUBA operation when the divers are working in pairs: each of the divers is the buddy for the other.

The buddy divers are jointly responsible for the assigned mission, and each keeps track of the depth and time factors for the dive. Each has a particular responsibility to watch out for the safety and well being of the other, being especially alert for symptoms of such maladies as nitrogen narcosis, decompression sickness, and carbon dioxide poisoning. A buddy diver must keep the other diver within sight and never leaves his partner alone except to obtain additional assistance when the diver is hopelessly entangled or entrapped.

Surface Crew 4.6.4 The tender is the surface member of the diving team who works most closely with the diver on the bottom. At the start of an operation, the tender checks the diver's equipment and topside air supply for proper functioning, dresses the diver, and, once the diver is in the water, constantly tends his lines to eliminate excess slack or tension. The tender exchanges line-pull communications with the diver, keeps the Diving Supervisor informed of the diver's depth and movements, ensures that the air supply is adequate, and remains alert for any signs of an emergency.

The tender should be a qualified diver. When circumstances require the use of a non-diver as tender, it is the responsibility of the Diving Officer and Diving Supervisor to ensure that he has been thoroughly and properly instructed in his duties. If during an operation a substitute tender must be employed, the Diving Supervisor must make certain that he is adequately briefed before he takes over the lines.

The timekeeper maintains worksheets and fills out the diving log (OPNAV form 9940/1) for the operation, and records the diver's descent time, bottom time, depth of dive, and monitors the decompression profile to ensure that the designated decompression schedule is followed. He usually operates the communications system, and notifies the Diving Supervisor of elapsed time.

The timekeeper is required to have on hand a copy of the USN Standard Decompression Tables. When decompression begins, he displays the schedule selected by the Diving Supervisor and keeps all members of the team advised of the status of the divers.

The timekeeper must be a qualified diver, and should not be assigned any additional duties which might interfere with his basic responsibilities. Also, because accurate timekeeping is so important to the safety of the divers, he should not normally be required to keep time on more than two divers simultaneously. In SCUBA operations, the Diver Supervisor often assumes the duties of the timekeeper.

Diving medical officers and diving medical corpsmen are given special training in hyperbaric medicine and in diving. They are regularly assigned to provide medical advice and treatment to diving personnel on a routine basis. They also instruct members of the diving team in first aid and emergency medical procedures, and participate in diving operations when the presence of diving medical personnel is indicated—as when particularly hazardous operations are being conducted. In some operations (e.g. air diving below 170 feet) the presence of a diving medical officer is mandatory.

Figure 4-25 The Diving Medical Officer keeps a close watch on a diver undergoing recompression treatment

Diving medical personnel certify the fitness of divers before operations begin and are prepared to handle any emergencies which might arise. They also observe the condition of surface-support personnel, being alert for signs of such problems as fatigue, overexposure and heat exhaustion.

Other surface-support personnel can include almost any member of the command when assigned to duties which support or coordinate with diving operations. Some personnel will be more directly involved and will need more specific indoctrination than others—for instance, the boat operators must be thoroughly familiar with diving procedures, must know the meanings of various signals, must understand the objectives of the mission, and must know how to operate a boat in connection with diving operations. Other personnel, such as winch operators or deck crew, might directly interact with the operation, but only when under the control of the Diving Supervisor. Still other members of the crew may not be directly involved, but can still have some type of interface with the operation. Engineering personnel, for example, may be directed to secure overboard discharges and lock the shafts; a sonar operator might be required to secure his equipment and put a "do not energize" tag on the power switch. (See Appendix F for a detailed Ship Repair Safety Checklist.)

Above all others, the Officer of the Deck (who, during his watch is responsible to the Commanding Officer for the operation and safety of the ship and the crew) will be concerned with the activities of the diving team. He must be kept informed of the progress of the operation and of any changes to the original plan, and should be notified as far in advance as possible of any special requirements (such as providing steam to a winch) which may be forthcoming.

Cross-Training and Substitution 4.6.5 Insofar as possible, each member of the diving team should be qualified to act in any position on the team. Operational plans should provide for an opportunity to gain such across-the-board qualifications, wherever possible. If, at any time during an operation, personnel changes must be made—whether temporary or permanent—the individual assuming the duty must first be certified by the Diving Officer or the Diving Supervisor as acceptable for that duty. He then must be thoroughly briefed on the mission, the status of operations, upcoming evolutions, and any anticipated problems. Since it is probable that substitutions will be made at some point during a lengthy mission, the general and diving schedules should organize personnel and work objectives so that highly experienced personnel will always be available onscene. Additionally, all personnel who will participate in the operation should be included in initial briefings.

Manning Levels 4.6.6 The size of the diving team may vary from one operation to the next, depending upon the type of equipment being used, the numbers 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 have an influence on the size of the team.

Recommended manning levels for a variety of diving teams are found in Figure 4-26. These are **minimum** levels, and should be adjusted appropriately to meet anticipated operational conditions and situations.

Physical Condition of Diving Personnel 4.6.7 Before a man can even begin training as a diver, he must meet the specific physical requirements for divers set forth by the Bureau of Medicine and Surgery (BUMED) as outlined in Appendix E. Once qualified, it is his own responsibility to keep in good health and in top physical condition.

Medical personnel assigned to a diving unit should take an active interest in the day-to-day condition of each diver, and the Diving Supervisor must verify the fitness of each diver immediately before a dive. Signs of any irregularity, such as a cough, nasal congestion, apparent fatigue, emotional stress, skin or ear infection, intoxication or any indication of the use of narcotics or other dangerous drugs, should put a man on the sick list until the problem is corrected.

The diver himself is often the best judge of his own physical condition. If he does not feel fit to dive, he is obligated to report that fact to the Diving Supervisor. A diver who, for any reason, sincerely does not want to make a dive should not be forced or penalized. A man who regularly declines diving assignments should be disqualified as a diver and given other duties.

BRIEF THE DIVING TEAM 4.7

The operations plan, no matter how well organized, will not result in a successful mission unless each member of the diving team fully understands the plan, his role in the plan, and the roles as well of other members of the diving team and of the various supporting personnel.

A briefing, just like a diving plan, can be elaborate or it may be very simple. For large operations, involving a number of units, a formal briefing with charts, slides and diagrams might be required. But for most operations, the briefing need not be complex and may take the form of an informal meeting.

The person conducting the briefing will normally be the Diving Supervisor—the man who will be in charge of all diving operations at the scene. During the brief-

RECOMMENDED MANNING LEVELS FOR VARIOUS TYPES OF AIR DIVING

	SCUBA Surface Crew			
	Optimum		Minimum	
DESIGNATION	**One Diver**	**Two Divers**	**One Diver**	**Two Divers** (D)
Diving Supervisor (C)	1	1	1	1
Diver	1	2	1	2
Standby Diver	1	1	1	1
Tender	1	2 (A)	1 (A-B)	2 (A-B)
Timekeeper/Recorder	1	1		
Total Men Required	5	7	4	6

	SURFACE-SUPPLIED AIR					
	Lightweight Gear		Deep-Sea Gear		Below 170 Feet	
DESIGNATION	**One Diver**	**Two Divers**	**One Diver**	**Two Divers**	**One Diver**	**Two Divers**
Diving Officer				1	1	1
Diving Medical Officer (Required)					1	1
Diving Supervisor (C)	1	1	1	1	1	1
Diver	1	2	1	2	1	2
Standby Diver	1	1	1	1	1	1
Tender	2 (B)	3	2	3	3	4
Timekeeper/Recorder		1	1	1	1	1
Total Men Required	5	8	6	9	9	11

NOTES:

A. One Tender per Diver required when Divers are surface-tended, if using Buddy System one Tender required for each Buddy pair.
B. Tender also acts as Timekeeper.
C. EOD Diving Officer required on scene for all EOD operations.
D. Four-man EOD team authorized to use two Divers.

Figure 4-26 Diving Team Manning Chart ing, he should cover all of the major points of the operation, including (but not limited to) the following:

- the objective and scope of the operation.
- conditions in the operating area.
- diving techniques and equipment to be used.
- personnel assignments.
- particular assignments for each diver.
- anticipated hazards.
- reiteration of normal safety precautions.
- discussion of any special considerations:
- group discussion period, questions from the diving team. In this period, the briefer should also direct questions at the team members, to verify that his briefing has been understood.

De-briefing the Diving Team 4.7.1 Prompt de-briefing of divers returning to the surface will provide the Diving Supervisor with information which 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 any suggestions they might have for immediate changes. 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 de-briefing of the day's activities. This offers all personnel a chance to provide "feedback" to the Diving Supervisor as well as to other members of the team. This group interaction can be of great help in clarifying any confusion which may have arisen because of faulty communications, distractions, or misunderstandings from the initial briefing.

MAKE FINAL PREPARATIONS AND CHECK ALL SAFETY PRECAUTIONS 4.8

Prior to the commencement of actual diving operations, the Diving Officer and the Diving Supervisor must review all progress and satisfy themselves that all appropriate preparations have been made. In summary, these are:

- a comprehensive diving plan has been prepared, and all data pertinent to the mission has been collected and analyzed for its impact on the operation and safety precautions.
- a task schedule has been prepared, with diving assignments clearly delineated and the sequence of events determined.
- requirements for both scheduled and emergency logistic support have been determined, and appropriate arrangements made.
- required equipment has been obtained, checked for proper operation, and is on station ready for use.
- emergency equipment (life jackets, fire extinguishers, resuscitator, first aid kit, etc.) has been checked for condition and is ready for use.
- all personnel, including any members of back-up teams, have been notified of their assignments, and a comprehensive briefing has been held.
- The General Safety Checklist has been reviewed (Appendix J).
- the On-Site Emergency Checklist has been prepared and posted.
- the Diving Officer and the Diving Supervisor have been given appropriate authority by the Commanding Officer.
- the qualifications and physical condition of all divers have been reviewed and certified.
- personnel are on station and ready to work.
- the ship or support vessel is properly moored and an anchor watch set.
- weather conditions are satisfactory for diving operations.
- higher authority (as appropriate) has been notified of the operation; other ships in the vicinity and the Harbor Master (if appropriate) have been notified.
- proper visual signals are displayed.
- the officer of the deck has been notified; he in turn has notified the Commanding Officer and the engineering officer, and has been given "permission to commence diving operations." ■

CHAPTER FIVE

AIR DIVING OPERATIONS (SCUBA)

A general description of Self-Contained Underwater Breathing Apparatus (SCUBA) was presented in Chapter One, along with a brief narrative covering the specific types of apparatus. Factors governing the utilization of SCUBA, and various planning considerations, are covered in Chapter Four, Operations Planning.

Of the three basic types of SCUBA (open-circuit, closed-circuit and semiclosed-circuit), only open-circuit normally uses compressed air as the breathing medium. Operation of this system will be covered in detail in this chapter. Operation of the other basic systems, which are designed for use with a mixture of gases other than air, will be found in Volume II of this Manual.

The SCUBA diver, more than any other, must have a high degree of confidence. He is placed in a situation where he is independent of his team members, without voice communications, usually without a lifeline and with a limited air supply. His ability to reason carefully and respond correctly in an emergency is a fundamental requirement for repeated success. In order to concentrate on the mission objectives, the SCUBA diver must have complete faith in his abilities and his equipment.

Formal training and experience combine to give the diver confidence in his ability. Beyond this, carefully established procedures, as presented in this chapter, will provide maximum assurance that each dive will progress as safely and efficiently as possible.

The material in this chapter includes:

- description of various approved SCUBA equipment and accessories
- pre-dive procedures
- SCUBA communications
- SCUBA diving technique
- safety precautions
- post-dive procedures, including field maintenance, stowage of equipment, and reporting

EQUIPMENT FOR SCUBA OPERATIONS 5.1

A certain minimum of equipment is required for every SCUBA dive: that which is necessary for the safety of the diver. This minimum may be augmented, as indicated by the nature of a given assignment, by items of optional accessory equipment.

Minimum Equipment 5.1.1 The minimum equipment which must be worn by every Navy SCUBA diver consists of the following:

- Open-circuit SCUBA
- Face Mask
- Life Preserver
- Weight Belt
- Knife and Scabbard
- Swim Fins
- Wristwatch } at least one
- Depth Gage } each per diving team

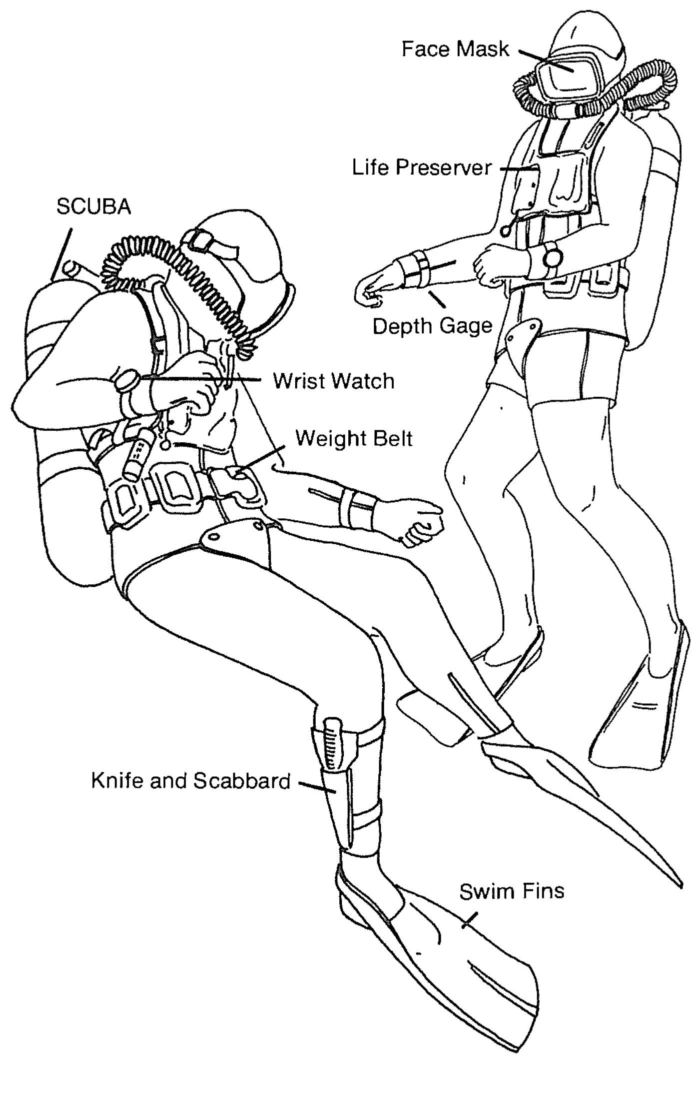


Figure 5-1 SCUBA diver with minimum equipment listed Above.

A variety of special equipment is available to a diver, most of which would be chosen to meet a specific operational requirement. Such equipment would include such items as underwater cameras, lifting bags, and the like.

OPEN-CIRCUIT SCUBA 5.1.1.1 There are two basic types of open-circuit SCUBA: the demand system and the continuous flow system. The demand system supplies air to the diver only when he takes a breath, while the continuous flow system directs a constant stream of air past his mouth, whether he is inhaling or exhaling. Because they are so wasteful of the air supply, continuous flow SCUBA systems are considered impractical. They are not authorized for use by Navy divers, and, therefore, they will not be discussed further in this chapter.

Every Navy-approved open-circuit SCUBA will include the following basic components*—

- demand regulator assembly
- mouthpiece assembly
- one or more air cylinders
- cylinder valve and manifold assemblies
- back pack or harness

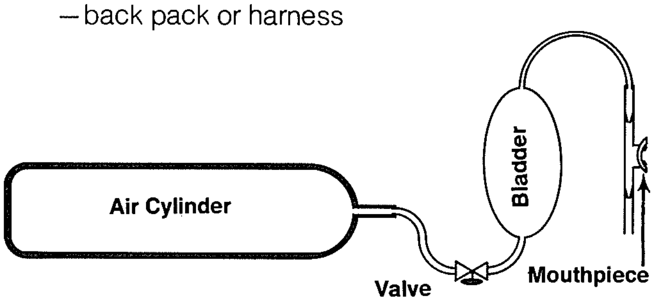


Figure 5-2 Schematic of continuous flow SCUBA.

The demand regulator assembly is the central component of the open-circuit system. The purpose of the regulator is to reduce the high pressure air in the cylinder to a pressure which can be used by the diver and to deliver the air, as required, at a sufficient flow rate. The specific operation of the demand unit may vary from one type of regulator to another, but the basic principle is the same for all. The operation of a common model of demand regulator is shown in Figure 5-3.

*A listing of all Navy-approved diving equipment is given in Appendix D.

There are two stages in a typical demand system. In the first stage, high-pressure air from the cylinder passes through a regulator which reduces the pressure to a level approximately 110 (±5)psi over the ambient pressure at the operating depth.

In the second stage, water at ambient pressure acts directly on one side of a moveable diaphragm. A low pressure air chamber is on the other side. The diaphragm is directly linked to the low pressure valve by the horseshoe lever. When the air pressure in the low pressure chamber equals the ambient water pressure, the diaphragm is in its center position and the low pressure valve is closed. When the diver "demands" air, the suction produced by his lungs reduces the pressure in the low pressure chamber causing the diaphragm to be pushed inward by the now higher ambient water pressure. The diaphragm actuates the low pressure valve which opens and permits air to flow to the diver. The larger the breath, the wider the low pressure valve is opened so that more air flows 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 one, or more, check valves and vents to the water.

Navy-approved demand regulator assemblies are manufactured in two basic types, single hose and double hose. Each is a two-stage system, and differs primarily in the placement of the stages.

In the single hose, two-stage demand regulator the first stage is mounted on the air cylinder, just after the cylinder valve. The second stage unit is located at the diver's mouth, in an assembly which includes the mouthpiece and a valve to exhaust ex-

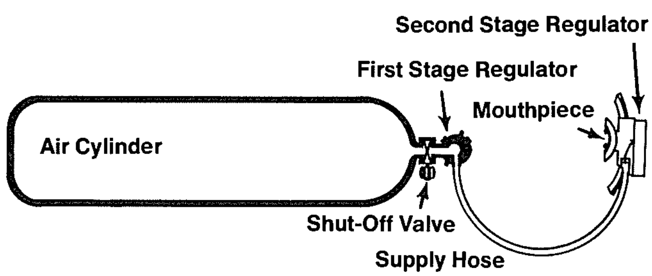


Figure 5-3 Schematic of single hose, two-stage demand regulator SCUBA.

Figure 5-4 Typical single hose SCUBA outfit.

haled air directly into the water. The two stages are connected by a length of durable, flexible medium-pressure hose, which passes over the diver's right shoulder.

The second stage also contains a purge valve, which, when pressed, passes the medium pressure air through the stage and the mouthpiece, blowing out any water which may have entered the system.

This purging feature is one of several advantages that the single hose system has over the double hose. Other advantages include reduced drag in the water from the single, smaller hose, and less opportunity for the hose to snag on underwater obstacles. The hose is stronger, since it must carry air at higher pressure, and is less susceptible to being torn or cut. Buddy-breathing, whereby one diver provides air from his SCUBA to his buddy, is more easily accomplished with the single hose regulator.

The principal disadvantage of the single hose unit is that the exhaust bubbles may rise in front of the diver's face, interfering with his vision. Another disadvantage, which was observed in a recent series of tests conducted in Alaska, is that the single hose regulator is more susceptible to freeze-up than the double hose unit. The reasons for this observed fact are presently being sought in a research effort being conducted by the Navy. Until the results of this effort are available, it is recommended that the single-hose regulator not be used in sub-freezing diving operations.

The double hose, two-stage demand regulator combines both the first and second stage regulators in a single assembly which is mounted on the cylinder valve assembly, behind the diver's head. A small

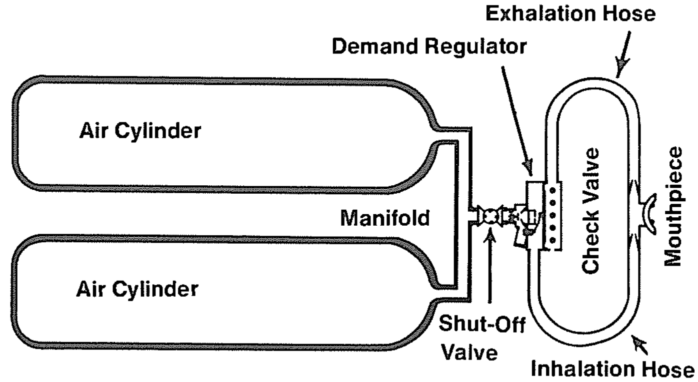


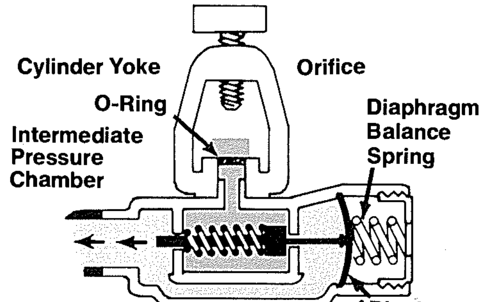
Figure 5-5 Schematic of double hose demand regulator

Figure 5-6 Typical double hose SCUBA.

intermediate chamber separates the stages, holding air at the pressure as designated by the first stage (about 110 psi over ambient pressure). When the diver takes a breath, the demand valve in the second stage opens, permitting this air, at ambient pressure, to flow through the second stage and into the intake hose supplying air to the diver's mouthpiece.

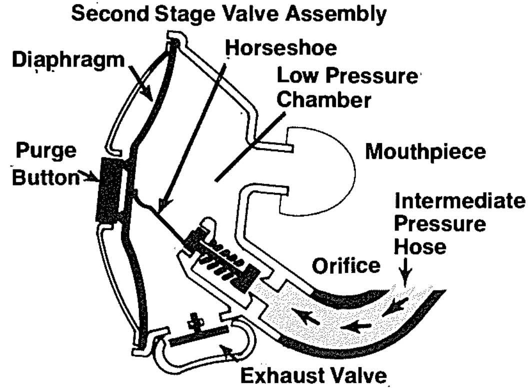
When the diver exhales, a check valve on the intake (right) side of the mouthpiece closes and another check valve on the exhaust (left) side opens. The exhaled breath passes through the exhaust hose and back into the regulator assembly. There, the air pushes past an exhaust flutter valve (which keeps

First Stage Valve Assembly



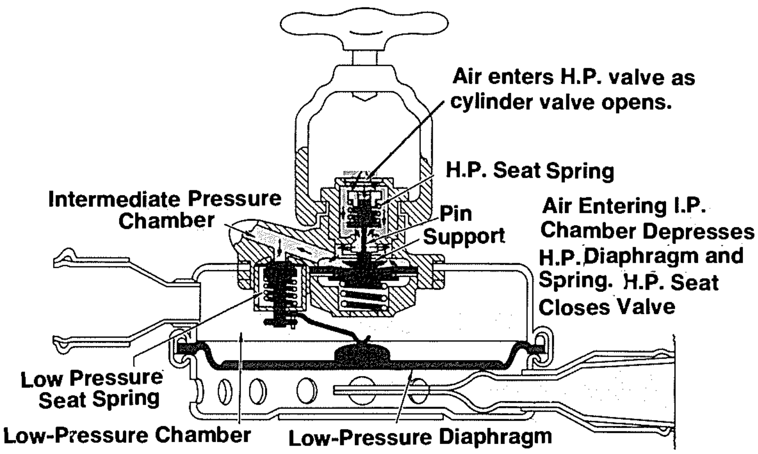
First Stage High pressure air flows through the orifice of the first stage into the intermediate chamber. When pressure in the intermediate chamber reaches ambient plus diaphragm balance spring set pressure, the first stage valve assembly closes.

Second Stage Valve Assembly

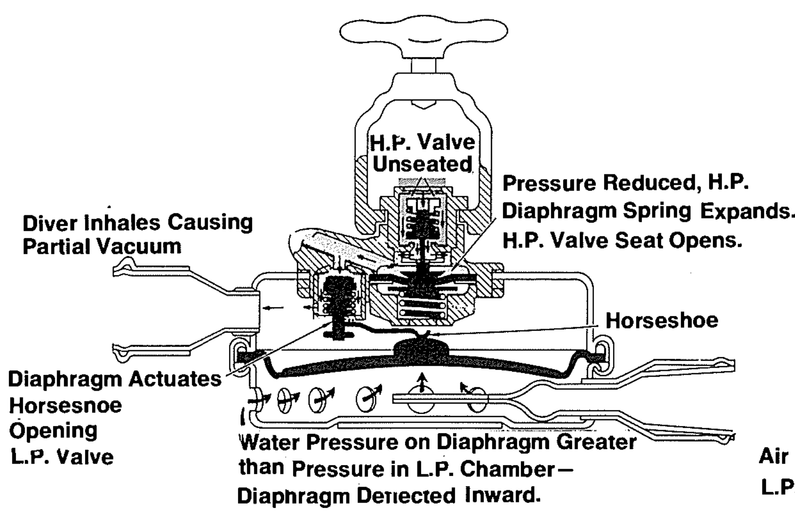


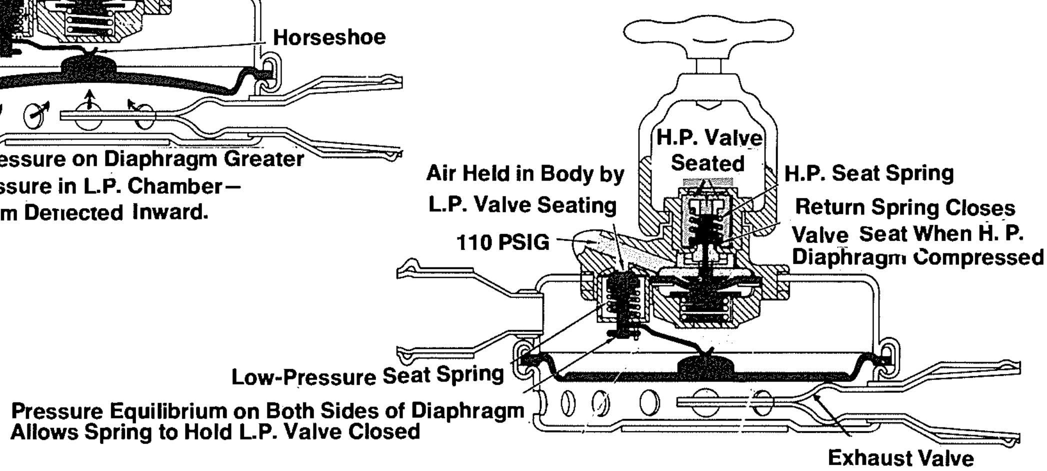
Second Stage Upon inhalation the second stage diaphragm moves inward and the horseshoe lever opens the second stage valve assembly. Intermediate pressure air from the hose is throttled across the orifice and fills the low pressure chamber to ambient pressure and flow is provided to the diver. Upon exhalation the diaphragm is pushed outward and the second stage valve is closed. Expired air is dumped from the low pressure chamber to the surrounding water through the exhaust valve.

SINGLE-HOSE REGULATOR



High-pressure air entering intermediate pressure area.





First and second stages of regulator in static (balanced) configuration.

Figure 5-7 Schematics of single hose and double hose demand regulator.

water from entering the system) into the exhaust chamber, and then to the surrounding water.

The double hose demand regulator, since it is mounted on the cylinder valve behind the diver's head, is often at a different pressure than that acting on the diver's cheeks. Because of this, a diver using a double hose system may find that his facial muscles start to fatigue during a dive. He may, as a result, find it difficult to hold the mouthpiece in his lips.

This difference in pressure will be dramatically experienced if the diver rolls over on his back. The demand valve in the regulator, now deeper in the water and under greater pressure than his lungs, will open, and air will free-flow through the system. If unexpected, this free-flow could force the mouthpiece out of the diver's mouth.

A major advantage of the double hose system is that the air in the supply hose is at a pressure approximately equal to that of the surrounding water. In the unlikely event of a rupture of the intake hose, air will slowly leak to the water at a rate which will not rapidly deplete the air supply in the cylinders.

The size and design of the SCUBA **mouthpiece** differ between the various manufacturers, but every mouthpiece serves one basic function: to provide a relatively watertight channel into the diver's mouth for his breathing air. The mouthpiece should fit comfortably, held in place by a slight pressure from the lips. Inexperienced divers tend to bite down on the mouthpiece, eventually chewing through the material.

The **cylinders** approved for Navy use (also called tanks or bottles) are of seamless, steel or aluminum construction. They are designed to hold compressed air at pressures of 2250 psig, for steel cylinders, and 3000 psig, for aluminum cylinders. Because of the extreme stresses imposed on a cylinder at these pressures, all cylinders used in SCUBA diving must be manufactured to precise specifications and periodically inspected and tested.

Each cylinder used in Navy operations must have identification symbols stamped into the shoulder, as shown in Figure 5-10.

Non-magnetic (aluminum) cylinders, manufactured under special Navy contract for use by Explosive

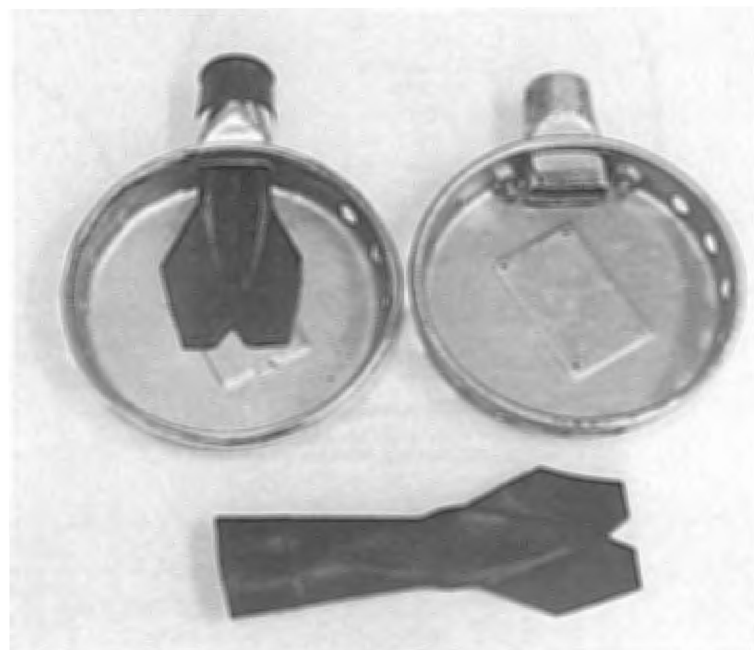


Figure 5-8 Flutter valve in double hose demand regulator

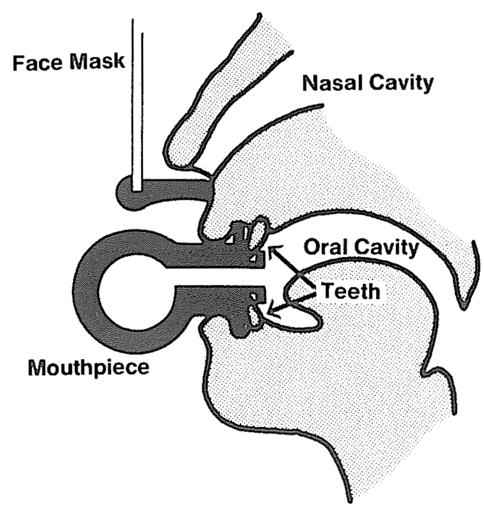


Figure 5-9 Diagram illustrates the proper position of the mouthpiece.

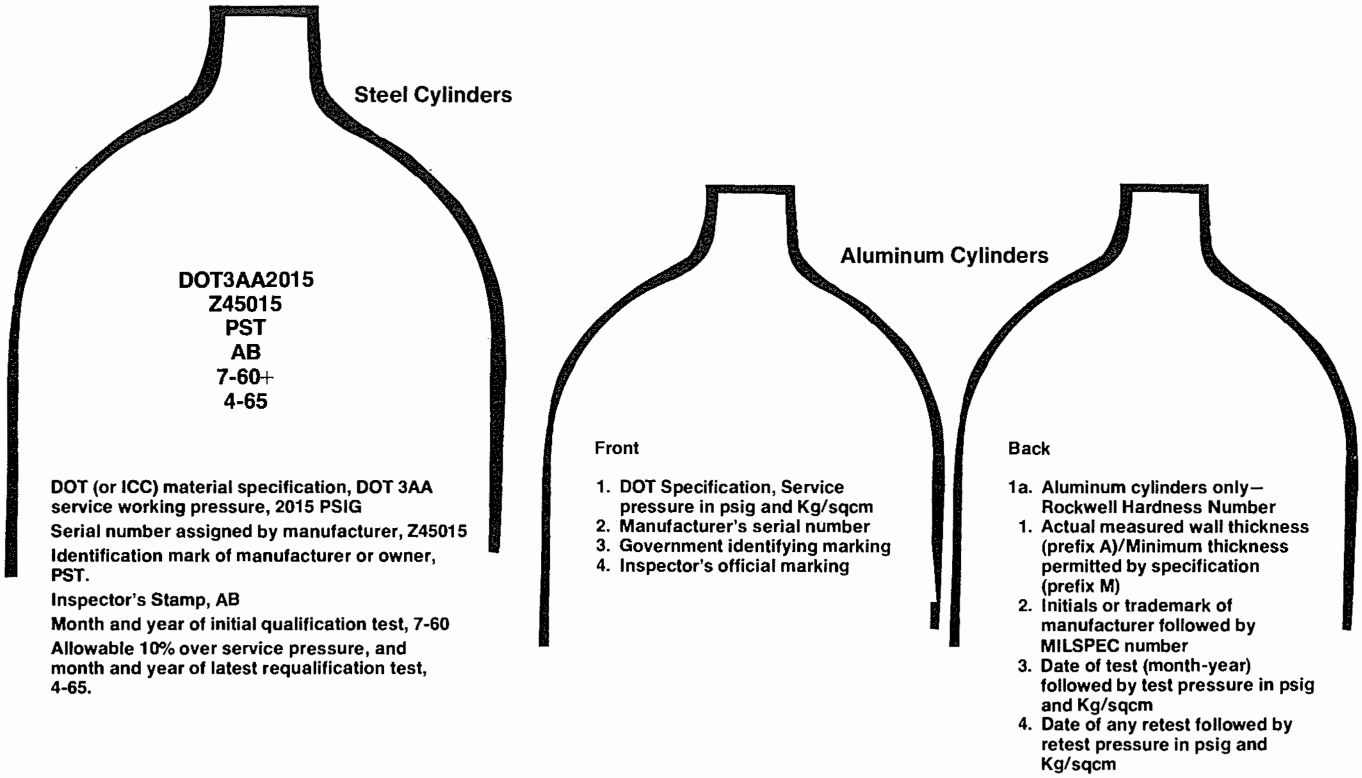


Figure 5-10 Gas cylinder identification markings.

Ordnance Disposal teams, will not bear DOT (formerly ICC) markings. Steel cylinders procured from commercial sources, outside normal Navy supply channels, will probably not have any special Navy markings but must meet DOT requirements.

Open-circuit SCUBA cylinders are to be visually inspected every time water or particulate matter is suspected in the cylinder, and at least once every twelve months. Cylinders containing visable accumulations of corrosion are to be cleaned before being placed back in service.

Steel cylinders must be hydrostatically tested every five years and aluminum cylinders every three years or whenever the cylinder may have been exposed to damage or when deterioration from any cause is suspected. Inspection, cleaning and testing procedures shall be conducted in accordance with NAVSHIP INST 9940.16 series.

Approved SCUBA cylinders are available in two sizes, and one or two cylinders may be worn to provide the required quantity of air during the dive. The **volume** of a cylinder, usually expressed in actual cubic feet or cubic inches, is the measure of the internal space of the cylinder. The **capacity** of a cylinder, expressed in standard cubic feet or liters, is the amount of gas (measured at surface conditions) which the cylinder holds when charged to its pressure rating. Table 5-1 lists the standard sizes of SCUBA cylinders.

General safety regulations governing the handling and use of compressed gas cylinders are contained in NAVSHIPS Technical Manual 9230. Persons responsible for handling, storing and charging SCUBA cylinders must be familiar with these regulations. Safety rules applying particularly to SCUBA cylinders are contained in Table 5-2. Because SCUBA cylinders are subject to continuous handling, and because of the hazards posed by a damaged unit, close adherence to these rules is mandatory.

Cylinder valves and manifolds make up the system which passes the high-pressure air from the cylinders to the first-stage regulator. The cylinder valve (also called the "tank valve") serves as an on/off valve, and contains a high-pressure blow-out plug (or disc) as a safety feature in the event of excessive pressure build-up. When a double manifold is used, two blow-out plugs are installed. Cylinders rated at 2250 psi use 3400 psi blowout plugs and cylinders rated at 3000 psi use 3900 psi blowout plugs. The plug rating is stamped on the face of the plug and cylinders with incorrect plugs installed must never be used or charged. The cylinder valve unit is sealed to the tank by a straight threaded male connection containing a neoprene "O" ring on the valve's body.

If two or more tanks are to be used together, a manifold unit will provide the necessary inter-connection. Any piping used in a manifold must conform to U.S. Navy specifications MIL-T-1368. When attaching manifolds and valves to the tanks and to each other, the connections must be compatible. Most units in use today incorporate an "O" ring as a seal, but some earlier models may have a tapered thread design. One type will not connect with the other.

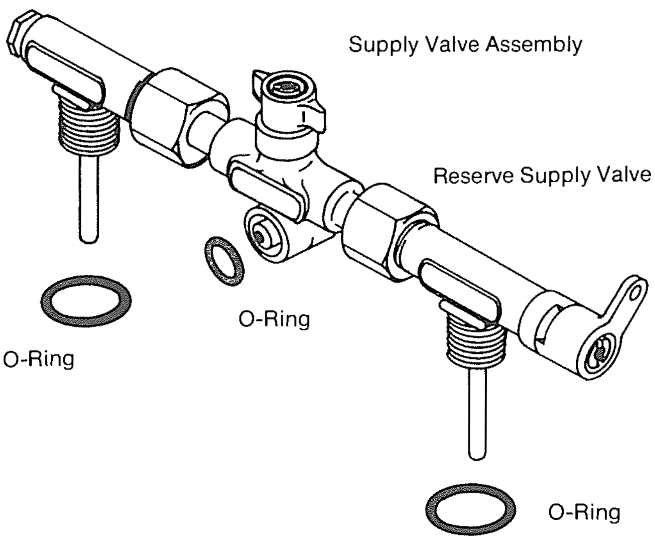


Figure 5-11 High pressure manifold

For all Navy SCUBA diving operations, the cylinder valve unit must contain an air-reserve mechanism. The standard Navy air-reserve mechanism is a manually-actuated "J" valve. There are other types, including an automatic design integral to the regulator, but these are not permitted since they do not provide a proper reserve function as discussed below.

The air-reserve mechanism serves two purposes: it gives warning to the diver that his air supply is almost exhausted, and it provides the diver with a quantity of reserve air, sufficient to enable him to reach the surface.

The usual air-reserve mechanism contains a spring-loaded check-valve which will begin to close as the air pressure in the cylinder falls to a pre-determined level, normally 300 or 500 psi. As this valve slowly closes, the air flow is reduced and the diver will find it increasingly harder to get a full breath. As soon as he notices this increased resistance to breathing, he should pull down the air-reserve pull rod which forces the check valve to open, making the remainder of the air in the cylinder available for breathing.

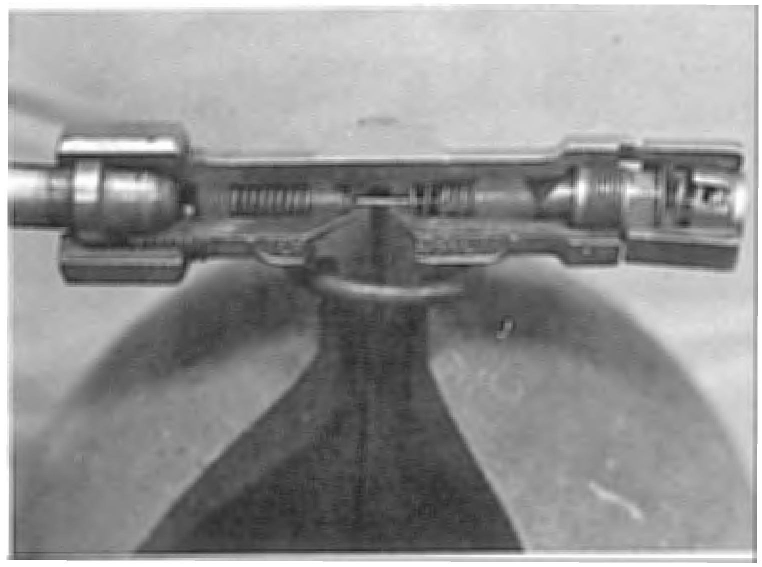


Figure 5-12 Air reserve mechanism

The diver should never assume that the reserve supply will be provided—the valve could have been damaged, the pull rod bent, or the pull rod might have accidentally been actuated earlier. When the resistance to breathing becomes obvious, the diver should routinely notify his buddy that he is low on air and they should both immediately start for the surface. THE DIVE MUST BE TERMINATED WHEN EITHER DIVER SHIFTS TO RESERVE AIR.

A variety of back-packs, or harnesses, used for holding the SCUBA on the diver's back have been approved for Navy use. The back-pack may include a light-weight frame with the cylinder(s) held in place with clamps or straps (not of quick-release type). The normal system for holding the unit on the diver uses shoulder, waist and crotch straps.

All straps must have a quick-release feature, easily operated by either hand, so that the SCUBA can be ditched in an emergency.

TABLE 5-1
SCUBA CYLINDER DATA

CYLINDER DESCRIPTION	RATED PRESSURE PSIG	WATER VOLUME INCHES^3	AIR CAPACITY SURFACE VOLUME FEET^3	LITERS	RESERVE PRESSURE PSIG	RECOMMENDED MINIMUM PRESSURE-PSIG
Open-Circuit Steel "72"	2250	835	71.2	2090	500	430
Open-Circuit Aluminum	3000	725	84.0	2380	500	600

TABLE 5-2
SAFETY PRECAUTIONS FOR CHARGING AND HANDLING CYLINDERS

1. Submerge the cylinder to be filled in a tank of water.
2. Make sure that the air reserve mechanism is OPEN.
3. Use only pure compressed air for filling cylinders, never OXYGEN. (The color code for air is black, and the color code for oxygen is green.)
4. Make sure that all fittings are tight before pressurizing lines.
5. Avoid excessive heat when charging.
6. When fully charged, CLOSE the air reserve; mark the tank as "filled" by putting masking tape over the cylinder valve. This also serves to prevent loss of "O" ring.
7. Store filled tanks in a cool, shaded area. Never leave filled tanks in direct sunlight.
8. Handle charged tanks with care: if damaged, or if the tank valve is accidentally knocked loose, the tank can become a lethal bomb. A tank charged to 2000 psi has enough energy to jet-propel itself through the air for some distance, tearing through any obstructions on the way.
9. Tanks should always be properly secured aboard ship or in the diving boat and not allowed to freely roll around.
10. Never work on a tank valve when the cylinder is charged, except to attach a SCUBA regulator, pressure gage, or to replace an "O" ring.
11. Always use reliable, properly calibrated gages to measure tank pressure. Never have your face near the dial of a gage to which pressure is being applied.
12. Do not attempt to fill any cylinder if the inspection date has expired or if it in any way appears to be substandard. Steel cylinders must be inspected every 5 years and aluminum cylinders every 3 years. Dents, severe rusting, bent valves, "frozen" reserve mechanisms, or evidence of internal contamination (water, scales of rust), are all signs of unsuitability.
13. Carry tanks by holding the tank valve and body of the cylinder only. Never carry a tank by the back pack or harness straps. The quick-release buckle can be accidentally tripped—or the straps might break.

FACE MASK 5.1.1.2 The face mask primarily protects the diver's eyes and nose from the water. As a secondary function it provides maximum visibility by putting a layer of air between the lens of the eye and the water, thus permitting the eye to focus on the transmitted images. This feature, however, is only minor in comparison to the psychological value of protecting the eyes and nose from the water.

Face masks are available in a variety of shapes and sizes. A diver should select the style which makes a seal and feels comfortable on his face.

Proper fit can be checked in two steps—

1. Holding the mask in place with one hand, inhale gently through the nose and let go of the mask. It should stay in place, held by the suction.
2. Put the mask on as it will be worn, with the head strap properly adjusted, and again 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, and some masks have "indents" at the nose or a neoprene nose pad to allow the diver to pinch off his nostrils to equalize the pressure in his 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. Selection of a mask with "special features" is a matter of personal preference or need. There is, however, one firm requirement which must be met in any face mask: the faceplate must be constructed of tempered or shatter-proof safety glass. Faceplates made of ordinary glass are a serious hazard to the eyes. Plastic faceplates, which are shatter-proof, are generally unsuitable because they fog too easily in use and are easily scratched.

The size or shape of the faceplate is another matter of personal choice, but the diver should seek a mask which provides the widest clear range of vision. Full-face masks, if they incorporate an oral-nasal inner mask, may also be used for Navy diving.

LIFE PRESERVER 5.1.1.3 A Navy-approved life preserver is a mandatory piece of equipment for SCUBA operations. The principal function is to assist a diver in rising to the surface and to maintain him on the surface in a head-up position. The automatic inflation device on the preserver may be actuated by the diver himself or by a buddy, should the diver be unconscious or otherwise unable to help himself.

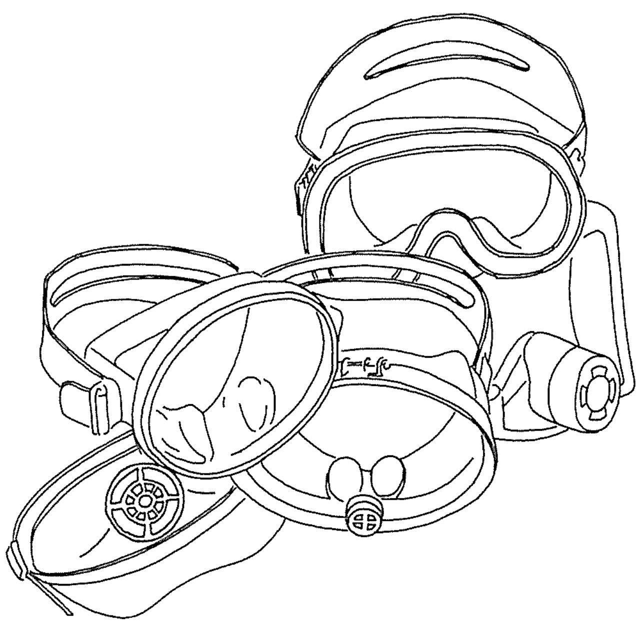


Figure 5-13 Typical, commercially available face masks

Figure 5-14 Modified UDT life preserver

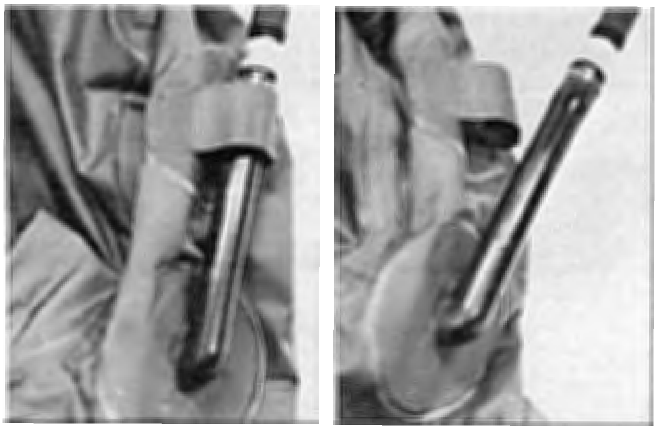


Figure 5-15 Oral inflation tube on UDT life preserver

Figure 5-16 MK 3 yoke-type life preserver

Two models of life preservers have been approved for Navy use with SCUBA: the **Modified UDT life preserver,** which is used primarily for surface swimming and shallow diving operations, (in water less than 36 feet), and the **MK 3 yoke-type model,** recommended for all other dives. Both models are equipped with oral-inflation tubes and automatic inflation systems employing small charges of liquid CO_2.

The modified UDT model uses an 18-gram CO_2 cartridge, providing a buoyant lift of 19 pounds at a depth of 18 feet. Below 18 feet, the lifting capacity of the charge is reduced by the increase in water pressure. The MK 3 has two inflatable chambers, each supplied by a pair of 31-gram CO_2 cartridges. This model has a lifting capacity of 19 pounds at 200 feet, with a positive surface buoyancy of 55 pounds. If cartridges for the modified UDT model are inadvertently used in the MK 3, the lift will be limited to 12 pounds at 200 feet. Conversely, 31-gram cartridges, if used in the UDT preserver, would over-inflate the preserver. Care must be taken to ensure that the proper cartridges have been installed in the life preserver.

Figure 5-17 Typical weight belt with quick-release clasp.

WEIGHT BELT 5.1.1.4 The SCUBA is designed to have nearly neutral buoyancy when in the water. In general, a unit with full tanks 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 neutral or slightly negative status.

This extra weight is furnished by the use of a weighted belt, worn outside of all other equipment and strapped so that it can be easily ditched in the event of an emergency. Each diver may select the style and size belt and weights which best suit him. A number of different models are available through commercial sources. However, any 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 irritate the diver's skin or damage any protective clothing; the belt itself should be made of a rot and mildew resistant fabric, such as nylon webbing.

Cartridge or pistol belts must not be used as weight belts: the "twist and hook" buckle cannot easily be released with one hand.

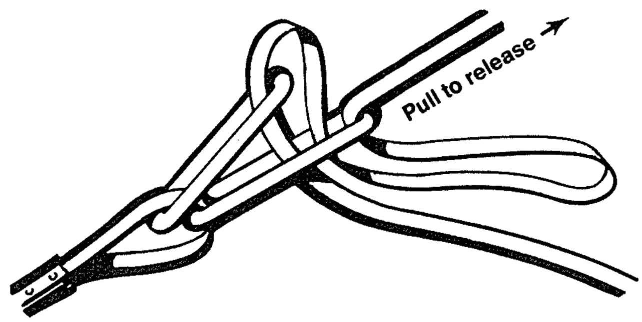


Figure 5-18 Accepted quick-release cylinder harness tie method.

KNIFE AND SCABBARD 5.1.1.5 Several types of knives are available as Navy issue: a standard diver's knife, a combat sheath knife, and, in limited quantities for divers engaged in missions which require it, a non-magnetic knife designed for use when diving near magnetic-influence mines.

Diving knives should have corrosion resistant blades, such as stainless steel, and a handle of plastic, hard rubber or wood. Handles made of wood should be waterproofed with paint, wax or linseed oil. Handles made of cork or bone should be avoided, as these materials deteriorate rapidly when subjected to constant immersion, especially in salt water. Cork also has a tendency to float the knife away from the diver.

Knives may have single or double edged blades, although a double edge is preferable. The most generally useful style is sharp on one edge and saw-toothed on the other. All knives, of whatever style, must be kept sharp.

The knife must be carried in a suitable scabbard, worn on the diver's hip, thigh or calf—the position being a matter of personal preference provided the knife is readily accessible and does not interfere with body movement while swimming or working. The scabbard should hold the knife with a positive but easily released lock.

The diver must not secure the knife and scabbard to the weight belt. If the weights are released in an emergency, the knife will be dropped at the same time and will not be available for use in any subsequent emergency.

SWIMFINS 5.1.1.6 Swimfins increase the efficiency of the diver, allowing him to move faster, farther, and to swim with a lower expenditure of energy.

Fins are manufactured from a variety of materials and in several styles. There are, however, two basic types: straight blade and offset blade. The straight blade directly extends the line of the foot, while the offset blade is set at an angle. This places the blade in a nearly horizontal position as the swimmer moves through the water. Both types are satisfactory, although the straight blade, because it requires a greater extension of the foot, may tend to bring on leg cramps sooner than the offset blade. Selection of type is a matter of personal preference, although swimfins with small or very "soft" blades should be avoided.

Flexibility, blade size and configuration each contribute to the relative "power" of the fin. A large blade will transmit more power from the legs to the water—providing that the legs are strong enough to use a larger blade. The diver should choose the combination of size and stiffness that gives him the best motive power without causing excessive fatigue. This is largely a matter of trial and error, and, as a diver gains in strength and experience, he will find his requirements changing.

The offset blade normally has a moulded-in socket for the foot, with the toe area left open. The straight blade normally has an enclosed toe and an open heel, the fin being held on by either a fixed or adjustable heel strap. This style should always be worn with protective footgear, such as rubber boots, to prevent irritation to the foot.

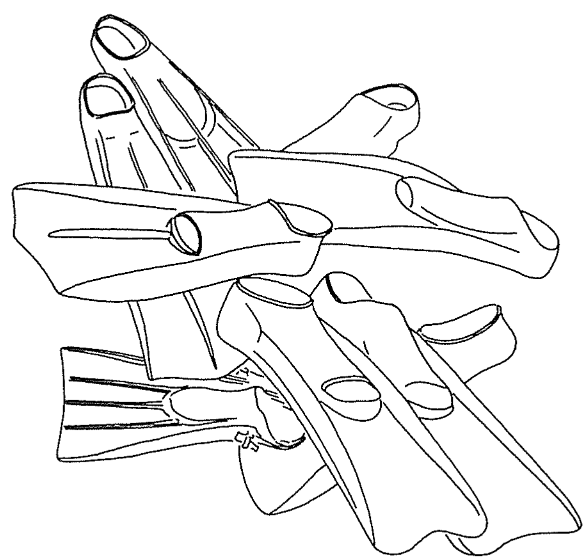


Figure 5-19 Various types of swim fins

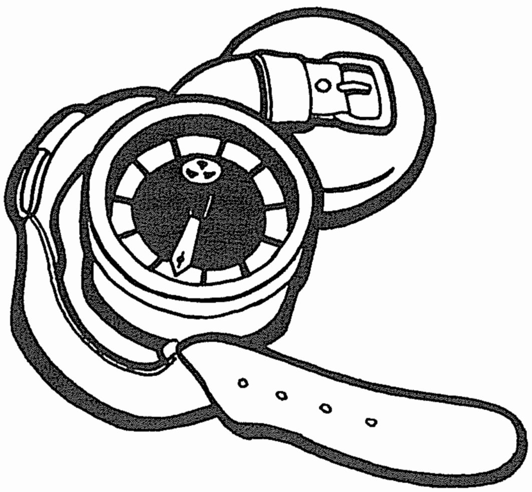


Figure 5-20 Wrist depth gage MK 1 MOD 0

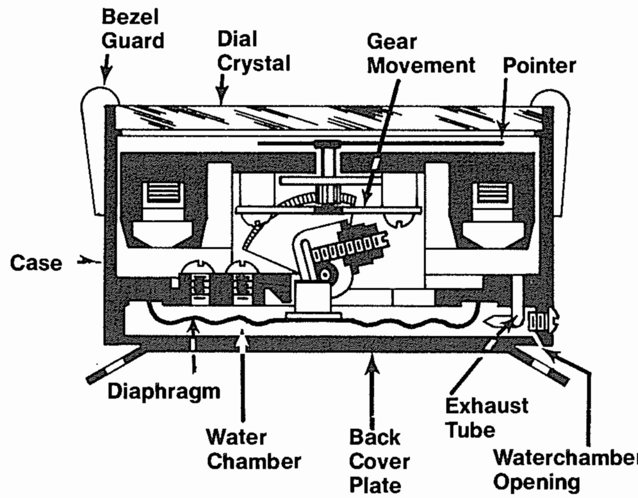


Figure 5-21 Cross sectional view of depth gage.

WRISTWATCH 5.1.1.7 Diver's watches must be waterproof, pressure-proof and equipped with a rotating bezel outside the dial which 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 can be obtained. A diver may select from a variety of Navy-approved watches obtained through commercial sources. The wristwatch should be worn on the same arm as the depth gage since the functions of the two are so closely related in the depth-time considerations of the dive.

DEPTH GAGE 5.1.1.8 The depth gage measures the pressure created by the water column above the diver and is calibrated to provide a direct reading of depth in feet. Depth gages are designed to be read under conditions of limited visibility and should be worn on the wrist, alongside the watch.

Depth gages approved for Navy diving operations are accurate to within one foot at depths to 50 feet, and within 3 feet at depths from 50 to 200 feet. The mechanism of the gage is relatively delicate and, like a watch, can be damaged by rough handling. Since accurate determination of depth is so important to a diver's safety, the accuracy of a gage must be checked at least every six months or whenever a malfunction is suspected. This can be done by either taking the gage to a known depth and checking the reading, or by placing it in a recompression chamber (make sure that the recompression chamber's depth gage has been calibrated). If recalibration of the gage is necessary, it should be carefully done in accordance with the manufacturer's instructions.

Optional Equipment 5.1.2 Depending upon the requirements of the specific diving operation, any or all of the following optional diving equipment may be necessary:

- Protective Clothing
- Slate and Pencil
- Signal Flares
- Lines
- Witness Float
- Light
- Whistle
- Tools
- Tool Bag
- Snorkel
- Wrist Compass

PROTECTIVE CLOTHING 5.1.2.1 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, or from the hazards posed by marine life and underwater obstacles.

Figure 5-22 Typical wet suit with hood and booties. Note signal flare and quick-release weight belt.

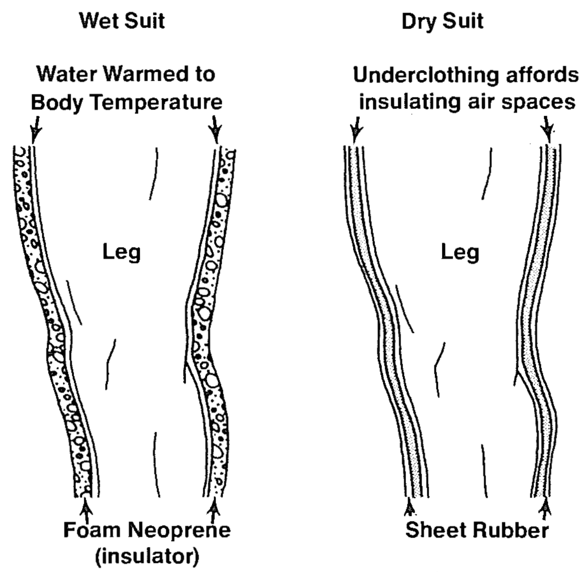


Figure 5-23 Comparison of wet and dry suits.

The most basic item of protective clothing is a pair of gloves. They can be made of leather, cloth or rubber, depending upon the degree and type of protection required. Gloves primarily shield the hands from cuts and chaffing, but normally they are not too effective in warding off the effects of cold water. Some styles are particularly designed to have insulating properties, but because of their thick construction severely limit the diver's dexterity.

Protection for the rest of the body may be provided by a wet suit, a dry suit, thermal underwear—or by some combination of the three.

The wet suit is a form-fitting suit, usually made of closed-cell neoprene. The suit is designed to permit a thin layer of water to be entrapped next to the diver's skin, where it is warmed by the heat from his body.

Wet suits are available in thicknesses of 1/8, 3/16, 1/4, 3/8 and 1/2 inch; the thicker the material, the better the insulation, but the more restrictive to movement. The selection of the type of wet suit used is left to the preference of each diver. Standard size suits, as well as custom fitted suits, are available at most commercial diving shops.

The most important factor in selecting a wet suit is to obtain a proper fit. The suit must not be so tight as to be uncomfortable or to restrict the diver's movements, but it must be snug. Whenever possible, a custom-fitted suit is recommended.

The performance of a wet suit depends on many variables, the prime ones being suit thickness, water temperature and depth, which governs the working thickness of the suit. Non-compressible wet suits are available which offer significantly better thermal protection than standard wet suits at depths below 50 feet.

The UNISUIT, a recently developed inflatable dry suit, has proven to be extremely effective in keeping divers warm in near-freezing water. It is constructed of 1/4 inch closed-cell neoprene with nylon backing on both sides. Boots are provided as an integral part of the UNISUIT, but the hood and 3-finger gloves are separate.

The suit is entered by means of a water and pressure proof zipper which runs from the breastbone down around the crotch and up to the base of the neck in back. Inflation is controlled using the inlet and outlet valves which are fitted in the suit. Air is supplied from either a low pressure takeoff on a two-stage single-hose regulator or from a pressure reducer on an auxiliary cylinder. Generally, about 0.2 actual cubic feet of air is required for normal inflation. Due to this inflation, slightly more weight than would be used with a standard wet suit must be carried on the diver's

Figure 5-24 Student diver wearing a dry suit.

Figure 5-25 Diver communication via a slate.

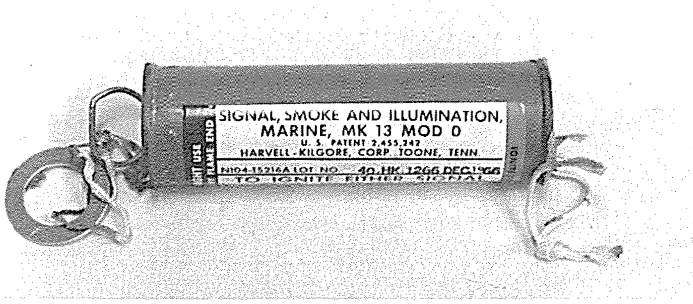


Figure 5-26 Mark 13 Mod O Signal Flare

weight belt, or alternately, weighted shoes may be worn over the boots.

By itself, the dry suit does not offer much thermal protection, so thermal underwear is normally worn under the suit for insulation. For even greater protection, a wet suit may be worn under the dry suit, functioning as heavy set of underwear.

Wet or dry suits can be worn with hoods, gloves, boots, or hard soled shoes, as conditions require. If the diver will be working under conditions where his suit may be easily torn or punctured, he should be provided with some additional protection in the form of coveralls or heavy canvas chafing gear.

SLATE 5.1.2.2 A sheet of acrylic, sandpapered on both sides to present a roughened surface, makes an excellent writing slate for recording data, for carrying or passing instructions, and for communicating with another diver underwater. A grease pencil or a regular graphite pencil should be attached to the slate with a lanyard.

SIGNAL FLARE 5.1.2.3 A signal flare is useful for attracting attention on the surface, particularly if the diver has surfaced too far away from his support crew to be noticed. Any waterproof flare which can be carried and safely ignited by a diver can be used, but the preferred type is the Mark 13 Mod 0. This is a dual day/night signal, giving off a heavy reddish orange smoke for daytime use and a brilliant red light for use at night. Each signal lasts for approximately 90 seconds. The night-end of the flare is identified by a ring of raised beads. When a flare is carried, it should not be fastened to the weight belt or to any other piece of equipment which might be ditched in an emergency. It also must not be fastened by its pull ring.

LINES AND FLOATS 5.1.2.4 A lifeline should be used in any situation where it is important to keep track of the diver's location, to be able to exchange signals with him, or where visibility is so poor that buddy divers could not otherwise keep track of each other. There are three basic types of lifelines: the surface line, the float line and the buddy line. In all instances of use, never attach a lifeline to a piece of equipment that may be ditched in an emergency.

One end of the surface line is secured to the diver and the other is tended from a surface craft. This line should be used when a diver is working without a buddy or when diving conditions seem particularly hazardous.

The float line reaches from the diver to a suitable "witness 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 witness float and gives a surfaced diver something to hang on to as well. If a pair of divers are involved in a search, the use of a common float will give them a simple rendezvous point. Additionally, various descending and messenger lines can be tied to the float, and tools or other equipment can be kept on the float, ready for use.

A buddy line, 6 to 10 feet long, is used to connect the buddy divers at night or in other conditions of poor visibility.

Any line used in SCUBA operations should be strong, and have neutral or slightly negative buoyancy. Nylon, dacron and manila are all suitable materials.

SNORKEL 5.1.2.5 A snorkel is a simple breathing tube which allows a diver to swim on the surface with his face in the water. This permits him to search a moderately shallow depth from the surface, conserving his SCUBA air supply. It also permits the diver to swim over a long distance without having to hold his head out of the water, which can become very tiring.

Snorkels are manufactured in a variety of models. Many of these incorporate a system of valves, intended to keep water out of the tube. Such an arrangement is basically unnecessary, since water which does enter the snorkel can easily be blown out. The valves and flaps only serve to complicate what is otherwise a simple, basic, and useful piece of equipment.

When snorkels are used for skin-diving, they are often attached to the face mask with a lanyard or rubber connector. For SCUBA work, where the snorkel is more of an accessory than a primary piece of equipment, it should be tucked under the belt when not in use.

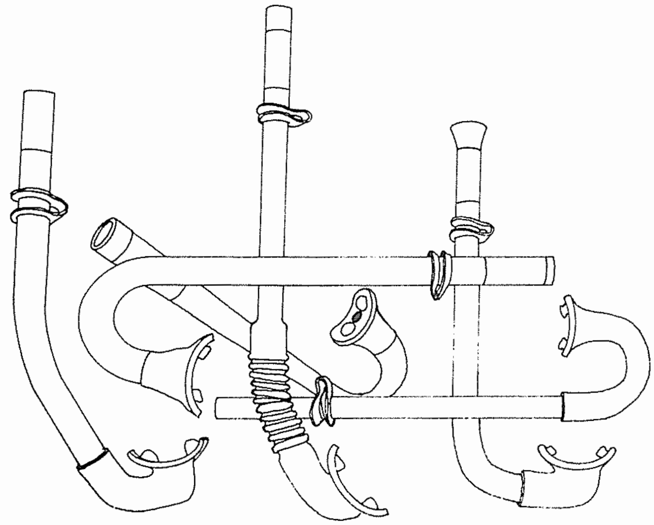


Figure 5-27 Commercially available snorkels

WRIST COMPASS 5.1.2.6 A small magnetic compass, worn on the wrist, is commonly used as an aid in underwater navigation. Such a compass is not particularly accurate, but it can nonetheless prove to be of great value, especially under conditions of poor visibility. The Mark I Mod I wrist compass is the only unit approved for use by Navy divers. When used, it should be worn on the arm opposite the one on which the depth gage and watch are worn to avoid magnetic interference.

A note on wearing wrist devices: straps should be of nylon, leather or plastic and should pass over both retaining pins and under the device. Expansion bands are not suitable, nor are any two piece bands which fasten on each side of the device. With a one-piece band, the device will still be held on the wrist even if one of the pins should fall out of place. Additionally, the strap should be large enough to fit over any protective clothing which may be worn, including, for example, both a wet suit and gloves if worn at the same time.

Hazardous Equipment 5.1.3

EARPLUGS AND GOGGLES 5.1.3.1 Never use earplugs. Earplugs keep water out of the external ear passages, making equalization of pressure impossible. The result could be an internal squeeze of the eardrum, or damage to the eardrum from the plug itself being forced into the ear. In a serious case, complete loss of hearing could result.

Never use goggles. Goggles do not enclose the nose and therefore the pressure inside cannot be equalized. Serious tissue damage can result from the water pressure forcing the rim of the goggles into the face, or the effects of squeeze tending to force the eyes into the goggles.

OTHER HAZARDOUS EQUIPMENT 5.1.3.2 Any equipment which is unnecessary to the particular dive, even though it may itself be a normal and "safe" piece of gear, is a potential hazard because it gives the diver more things to keep track of or to have get in his way.

Any equipment not on the approved list—especially any items which fall into a general category of "gadget"—should not be used. An example of this type of gear is a decompression meter, available on the commercial market. A Navy diver **must** use the Standard Decompression Tables, and reliance on any such mechanical device is prohibited without special approval.

PREPARATIONS FOR SCUBA DIVING OPERATIONS 5.2

Before any diving operation may begin, three basic steps must be taken. First, the air supply must be provided. Second, all equipment must be assembled and thoroughly checked. Third, the diver must be dressed and given his final pre-dive briefings.

THE AIR SUPPLY 5.2.1 A detailed discussion of all aspects of air supply systems is presented in Chapter Six. The following discussion is generally limited to the subject of air supply systems to be used in SCUBA diving.

The air used in any diving operation must meet four basic requirements—

- —The air must meet all purity standards of the Bureau of Medicine and Surgery.
- —A sufficient volume of air supply must be available to meet planned requirements plus an allowance for an adequate reserve.
- —The delivery system must provide a sufficient flow of air to the diver.
- —The system must deliver air to the diver at the proper pressure.

An important early step in preparing for any SCUBA dive is to compute the air supply requirement, and then to ensure that the required supply will be available at the time of the dive. Since the air supply is furnished in cylinders of definite capacity, requirements are directly linked to the duration of the air supply, at working depth.

The following sections will present—

- —a step-by-step demonstration of the recommended method for calculating duration of air supply.
- —sources and standards for air used in SCUBA.
- —methods for charging SCUBA cylinders.
- —safety precautions for charging and handling cylinders.

DURATION OF AIR SUPPLY 5.2.1.1 The duration of air supply of any given cylinder or combination of cylinders is dependent upon the diver's consumption rate, the depth, and the capacity and recommended minimum pressure of the cylinder(s). The effect of temperature is usually not significant in computing the duration of the air supply, unless the temperature conditions are extreme. In this event, the relationship discussed in Chapter Two (Charles' Law) must be applied.

The duration of the air supply of the various approved SCUBA cylinders, singles and doubles, may be read directly off the charts shown in Table 5-3, or it may be calculated as shown below.

A diver's consumption rate, or respiratory minute volume, varies depending upon how hard he is working. Figure 5-28 shows this basic relationship.

Since the quantity of air in each "actual cubic foot" breathed by the diver will be influenced by the depth and the temperature of the air at depth, the consumption rate in standard cubic feet per minute must be determined.

$$C = \frac{D + 33}{33} \times Rm \times F_{TD} \qquad \text{(equation 5-1)}$$

Where,

C = Diver's consumption rate, scfm

D = Depth, f. s. w.

Rm = Diver's respiratory minute volume, acfm

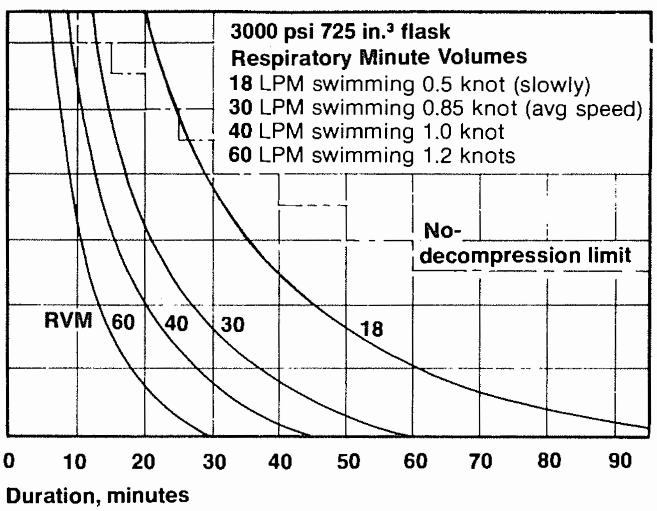
F_{TD} = Temperature factor at depth

The temperature factor (F_T) is dependent upon the temperature of the air at depth as follows—

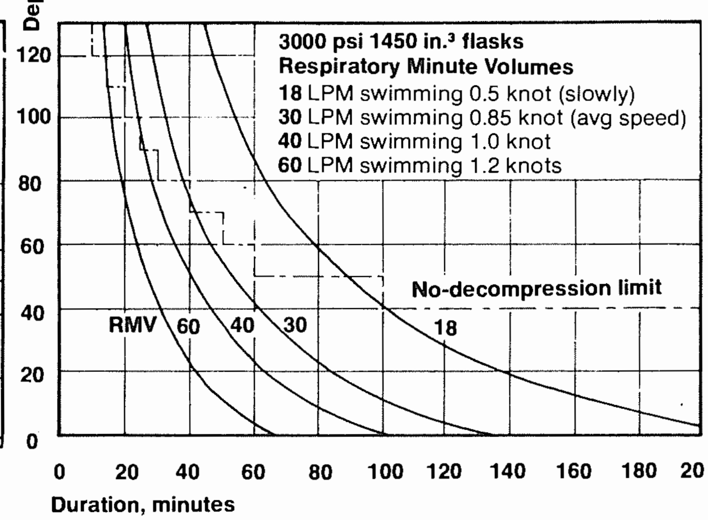
Temperature	F_{TD}
40°F	1.07
70°F	1.00
100°F	0.94

TABLE 5-3
DURATION OF AIR SUPPLY—SCUBA CYLINDERS

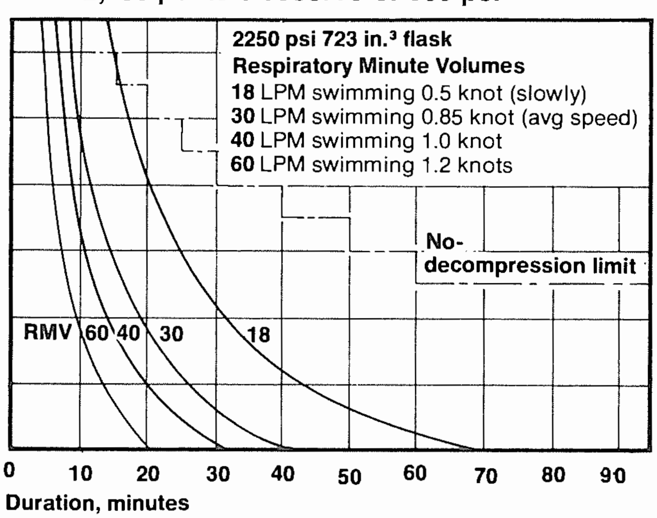
DURATION OF SINGLE ALUMINUM 90-SCF SCUBA CYLINDER
From 3,000 psi to a reserve of 500 psi



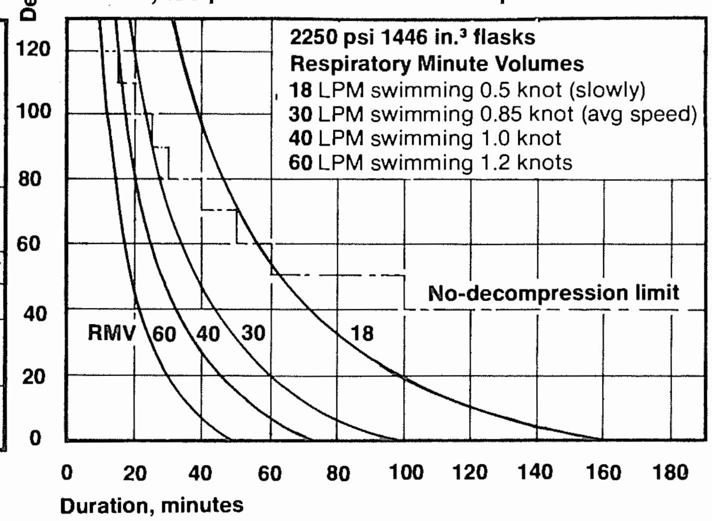
DURATION OF TWIN ALUMINUM 90-SCF SCUBA CYLINDERS
From 3,000 psi to a reserve of 500 psi in one flask



DURATION OF SINGLE STEEL 72-SCF SCUBA CYLINDER
From 2,250 psi to a reserve of 500 psi



DURATION OF TWIN STEEL 72-SCF SCUBA CYLINDER
From 2,250 psi to a reserve of 500 psi in one flask.



The capacity of air which will be provided by a given cylinder must be expressed as the capacity of air which will actually be available to the diver, rather than as a total capacity of the cylinder. This available capacity may be determined as—

$$V_a = \frac{V_c(N)(P_c - P_{rm})}{P_r} \qquad \text{(equation 5-2)}$$

where,

V_a=Capacity available, scf.

V_c=Rated capacity of cylinder, scf.

N=Number of cylinders

P_c=Measured cylinder pressure, psig.

P_{rm}=Recommended minimum pressure of cylinder, psig.

P_r=Rated pressure of cylinder, psig.

FTS= Temperature factor at temperature where cylinders are stored.

To determine the duration, in minutes, of this available capacity, divide the capacity available (scf) by the consumption rate (scfm).

$$\text{Duration} = \frac{V_a}{C} \qquad \text{(equation 5-3)}$$

Example—

Problem—Determine the duration of air supply to a diver doing moderate work at 70 feet using twin "72" cubic foot cylinders charged to 2000 psig.

Solution—The diver's consumption rate at depth is determined from Figure 5-28 to be 1.2 acfm. Calculate this consumption rate in standard cubic feet per minute using equation 5-1.

$$\text{Consumption Rate} = \frac{70 + 33}{33} \times 1.2 \ \times 1.0$$

Consumption Rate=3.75 scfm

Table 5-1 gives the following data for "72" cubic foot cylinders—

Cylinder rated capacity	=71.2 scf
Cylinder rated pressure	=2250 psig
Recommended minimum pressure	=430 psig

Using these values in equation 2—

$$Va = \frac{71.2\,[2000 + (2000 - 430)]}{2250}$$

$$Va = 113 \text{ scf}$$

The duration of the air supply is found from equation 3—

$$\text{Duration} = \frac{113 \text{ scf}}{3.75 \text{ scfm}}$$

$$= 30.1 \text{ minutes}$$

In this example, the total time for the dive, from initial descent to surfacing at the end—is limited to less than 30.1 minutes.

STANDARDS FOR AIR 5.2.1.2 Air used in SCUBA operations must meet standards of purity as established by the Bureau of Medicine and Surgery. This is true no matter what the source of the air or the method used for charging the cylinders. These standards are—

—Oxygen concentration	20 to 22 per cent by volume
—Carbon dioxide	0.05 per cent (500 ppm)
—Carbon monoxide	0.002 per cent (20 ppm)
—Oil—mist or vapor	5 milligrams per cubic meter maximum
—Solid and liquid particles	Not detectable except as noted above under oil—mist or vapor
—Odor	Not objectionable

Air supplied through a high pressure air compressor should be analyzed at regular monthly intervals. High pressure air cylinders should also be analyzed every month unless they are stored and remain unused for extended periods. In this case, the contents should be analyzed every six months. Presently, equipment for analyzing air is not available at most of the sources which supply diving air. Air samples must be taken using evacuated sampling flasks provided for this purpose and submitted to a qualified laboratory for analysis.

SOURCES OF AIR 5.2.1.3 Compressed air which meets the established standards can usually be obtained from the following Navy sources—

- —Torpedo shops
- —Naval Air Stations
- —Submarine Tenders
- —Submarine Rescue Ships
- —Destroyer Tenders
- —Aircraft Carriers
- —Explosive Ordnance Disposal (EOD) Teams

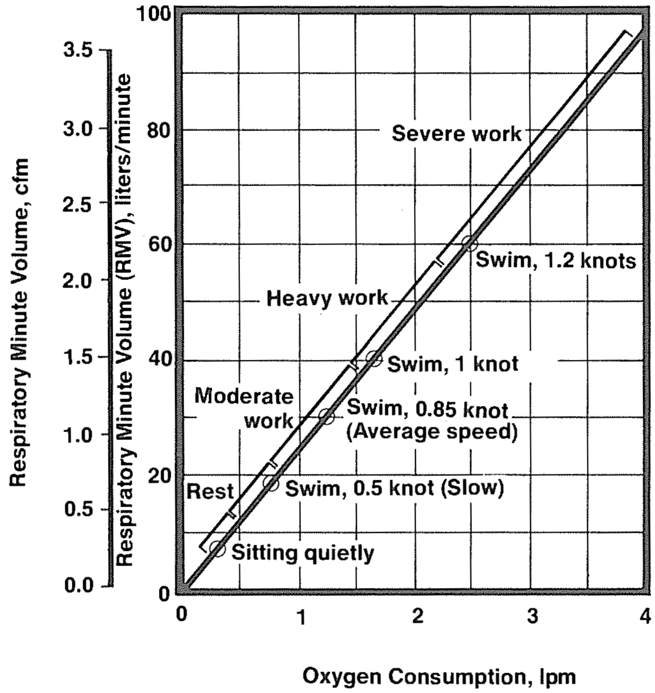


Figure 5-28 Relation of respiratory volume and oxygen consumption to type and level of exertion

- Underwater Demolition Teams (UDT)
- Naval Shipyards and Repair Facilities
- Underwater Construction Teams (UCT)
- Naval Mobile Construction Battalion Diving Lockers

In the absence of appropriate naval facilities, air may be procured from commercial sources. Any civilian agency or firm which handles compressed oxygen can usually provide pure compressed air. Air procured from commercial sources must meet the requirements of FED SPEC BB-A-1034A. Air procured from any source must be contained in cylinders which meet required legal standards for high-pressure compressed air. Cylinders must bear a serial number, a DOT inspection stamp, a pressure rating and the date of the last hydrostatic test.

METHODS FOR CHARGING SCUBA CYLINDERS

5.2.1.4 It is often impractical to obtain ready-service supplies of air in the form of filled SCUBA cylinders. The diving unit (which may be attached to one of the primary "sources" of air previously listed) will usually charge its own cylinders by one of two accepted methods—

Figure 5-29 Gaging SCUBA cylinders

- Cascading, or transferring air from banks of large cylinders into the SCUBA tanks.
- High-pressure air compressor.

Cascading is the fastest and most efficient method for charging SCUBA tanks. The normal cascade system will include a minimum of three 220 or 270 cubic foot cylinders, (designated A, B, C, etc.) manifolded together and feeding into a special SCUBA high-pressure "whip." This whip consists of a SCUBA yoke fitting, a pressure gage, and a bleed valve for relieving the pressure in the lines after charging a cylinder. A cascade system, with attached whip, is shown in Figure 5-30.

SCUBA tanks are charged in the following manner—

A. Check the existing pressure in the SCUBA cylinder, using a reliable pressure gage. If the reading is below 50 psig, the residual air may have become contaminated by an infusion of impure outside air. In such a case, the cylinder must either be completely evacuated with a vacuum pump or charged to a level of 300 psig and then discharged through two complete cycles.

B. When satisfied that the cylinder is not contaminated, attach it to the yoke fitting on the whip. For safety (in the event of an exploding cylinder) and for efficiency (to dissipate heat generated in the charging process) it is advisable, when facilities are available, to immerse the SCUBA cylinder in a tank of water while it is being filled. A 55-gallon drum makes a suitable container for this purpose.

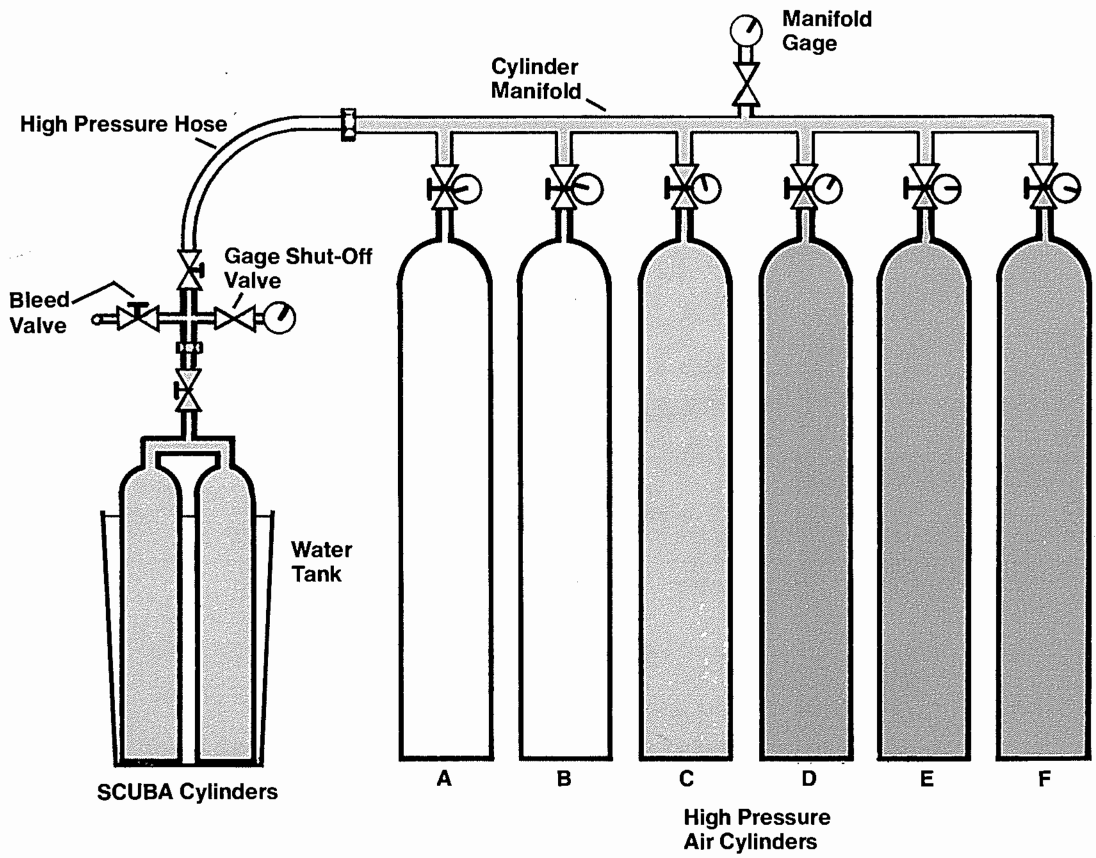


Figure 5-30 Cascading system for charging SCUBA cylinders

C. Make sure that all fittings in the system are tight.

D. Close the bleed valve, open the cylinder air reserve mechanism and cylinder valve. This valve (the on/off valve) is fully opened with about two turns of the handle, counter-clockwise. However, the valve must not be used in a "fully open" position as it might tend to stick or be easily stripped by a diver trying to force open a valve that he thinks is closed. The proper procedure is to open the valve all the way, and then back-off 1/4 to 1/2 turn. This will not materially impede the flow of air.

E. Slowly open the valve on cylinder A. The sound of the air flowing into the SCUBA cylinder will be noticeable. Control the flow so that the pressure in the cylinder increases at a rate not to exceed 400 psig per minute. The rate of filling must be controlled to prevent overheating; the cylinder should never be allowed to become too hot to touch.

F. After a time the pressure in cylinder A and in the SCUBA cylinder will equalize and the audible flow of air will cease. Close the valve on cylinder A, and slowly open the valve on cylinder B. Again, control the rate of flow to limit the pressure change to 400 psig/minute.

G. The pressure gage should be closely watched, and when the reading approaches the rated-pressure for the SCUBA cylinder, the valve on cylinder B should be closed and an accurate reading made.

H. If the pressure between cylinder B and the SCUBA cylinder has equalized before the rated pressure is achieved, close the valve on cylinder B and slowly open the valve on cylinder C until the desired pressure has been reached.

I. Close the valve on the charging cylinder. Close the on/off valve on the SCUBA cylinder. Check to see that all valves in the system are firmly closed. Wait for the SCUBA cylinder to cool to room temperature. (Without a water bath, this could take as long as two hours).

J. When the cylinder has cooled, the pressure will have dropped. Open the on/off valve on the SCUBA cylinder and then the valve on cylinder C to bring the pressure up to the rated limit. Then close all valves.

K. Open the bleed valve and de-pressurize the lines. When air has stopped flowing through the bleed valve, disconnect the SCUBA cylinder from the yoke fitting. Close the air reserve mechanism (place pull rod in the "up" position) to signify a full cylinder ready for use. Additionally, it is a good practice to put a piece of masking tape over the cylinder valves. This helps to keep out dirt, and is another means for identifying a full SCUBA cylinder.

These procedures can be repeated to fill additional SCUBA cylinders. Eventually, the pressure in cylinder A will reach a level of 300 psig, at which time that cylinder must be removed from the system. Cylinder B now replaces cylinder A, and cylinder C likewise replaces cylinder B. A new cylinder is put on the line, taking the place of cylinder C. Alternatively, the entire bank can be re-charged (if an adequate compressor is available). This is often the preferable method because moving the large air cylinders, especially aboard a ship that is rolling and pitching, can be both difficult and hazardous.

Air compressors can be used to directly charge SCUBA cylinders, but because of the high pressure required few compressors can deliver air in sufficient quantity for efficient operation. For example, the capacities of various portable compressors range from 0.3 to 1.5 cubic feet per minute. At these rates, it could take as long as four hours to fill one 72-cubic foot cylinder.

If a suitable compressor is available, the basic charging procedure will be the same as that outlined for

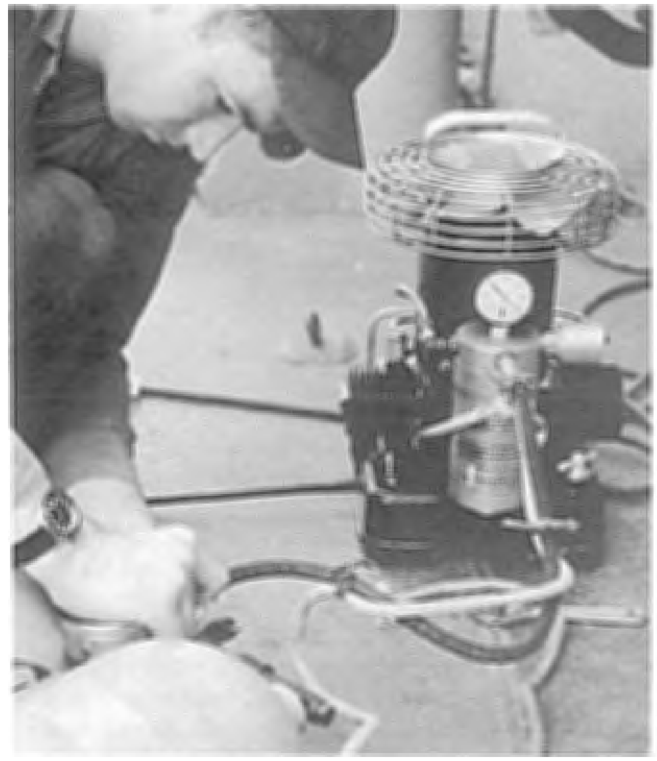


Figure 5-31 Typical air compressors

cascading except that the compressor will replace the bank of cylinders. Special considerations which apply to the use of air compressors are—

—the compressor must deliver air at the established standards of purity.

—the compressor should be equipped with filters to remove impurities from the air. These should be regularly checked and cleaned.

—the standards for inspection and maintenance, outlined in the NAVSHIPS Technical Manual (Chapters 9490 and 9940) must be carefully met.

—an engine-driven compressor must always be mounted so that there is no danger of taking in exhaust fumes from the engine or other contaminated air from local sources.

—only approved lubricants, as discussed in Section 6.2.2.1 of Chapter Six are to be used.

Additional information on the use of air compressors will be found in Chapter Six.

Equipment Preparation 5.2.2 Prior to any dive, all equipment must be carefully inspected for signs of deterioration, damage or corrosion and must be tested for proper operation where required. The procedures which follow have resulted from many years of diving experience and are to be carefully followed. Pre-dive preparation procedures must be standardized, must never be altered in the interests of "convenience," and must be the personal concern of each diver. Every diver must always check his own equipment and must never assume that any piece of equipment is ready for use unless he has personally verified that readiness, even if other personnel have been assigned to prepare and check-out the equipment.

Table 5-4, a general checklist for Equipment Preparation, contains step-by-step instructions for thorough pre-dive inspection and testing of all equipment.

Figure 5-32 Navy team checking and preparing equipment prior to a diving operation.

TABLE 5-4
EQUIPMENT PREPARATION (SCUBA)

GENERAL CHECKLIST

Air Cylinders

Inspect for rust, cracks, dents or any other evidence of weakness or fault. Pay particular attention to loose or bent valves.

Check cylinder markings and verify suitability for use. Check that the hydrostatic test date has not expired.

Remove masking tape and/or valve cover and inspect O-ring and valve threads.

Verify that the reserve mechanism is in a closed position signifying a filled cylinder ready for use.

Gage the cylinders according to the following procedure:

1. Attach pressure gage to the on/off valve.
2. With gage bleed valve closed and air reserve mechanism open, slowly open the cylinder on/off valve, keeping a rag over the face of the gage.
3. Read pressure gage. If the pressure in the cylinder is not sufficient to complete the planned dive, the cylinder is inadequate and should not be used until it is filled.
4. Close the cylinder on/off valve and open the gage bleed valve. When the gage reads "O" remove it from the cylinder. Close the air reserve mechanism. If the pressure in cylinders is too high (50 psi over rating) open the cylinder on/off valve to bleed off excess and re-gage cylinder.

Harness Straps and Back-Pack

Check for signs of rot or excessive wear. Adjust straps for individual use, and test quick-release mechanisms.

Breathing Hoses

Check the hose(s) for cracks or punctures. Test the the connections of each hose to the regulator and mouthpiece assembly by tugging on the hose. Check the clamps for corrosion and damage; replace as necessary.

TABLE 5-4 — cont'd

Regulator

Attach regulator to the cylinder on/off valve, making certain that the O-ring is properly seated. Open the cylinder valve all the way and then back off ¼ turn. Check for any leaks in the regulator by listening for the sound of escaping air.

If a leak is suspected, determine the exact location by submerging the valve assembly and the regulator in a tank of water and looking for bubbles. Frequently the problem can be traced to an improperly seated regulator. This is corrected by closing the valve, bleeding the regulator, detaching and reseating.

If leak is at the O-ring, and re-seating does not solve the problem, **replace the O-ring.**

With either a single-hose or a double-hose unit, the hose supplying air should come over the diver's right shoulder with the exhaust hose on the double-hose unit passing back over his left shoulder. Double-hose regulators are attached so that the inhalation and exhaust ports face up when the tank is standing upright.

Inhale and exhale **several times** through the mouthpiece, making sure that the demand stage and check valves are working correctly. 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. Close the cylinder on/off valve.

Life Preserver

Orally inflate to **check for leaks,** and then squeeze all of the air out. The final amount of remaining air in the vest should be sucked out so that the preserver is **completely empty.**

Inspect the **CO_2 cartridges** to make sure that they have not been used (seals intact) and are the proper size for the vest being used. The cartridges should be weighed every six months and discarded if the weight varies more than 3 grams from the gross weight stamped on the cartridge. Ref. Chap. 9331, Art. 32 of NAVSHIPS Technical Manual.

The **firing pin** should move freely and not be worn.

The **firing lanyards** and life preserver **straps** must be free of any signs of deterioration. When inspection of the preserver is completed, place it where it will not be stepped on or mixed in with other equipment that may damage it. Life preservers should **never** be used as a buffer, cradle, or cushion for other gear.

Face Mask

Check the seal of the mask and the condition of the head strap. Check for cracks in the skirt and faceplate.

Swim-Fins

Check straps and inspect blades for any signs of cracking.

Diving Knife

Test the edge of the knife for sharpness, and make sure that the knife is fastened securely in the scabbard. Verify that the knife can be removed without difficulty.

Snorkel

Inspect the snorkel for obstructions, and check the condition of the mouthpiece.

Weight Belt

Check that the belt is in good condition and that the proper number of weights are in place and secure. Verify that the quick-release buckle is functioning properly.

Wristwatch

Check that the watch is wound and set to the correct time. Inspect the pins and strap of the watch for wear.

Depth Gage and Compass

Inspect pins and straps on each. Make sure depth gage is properly calibrated. If possible, check compass against another compass.

General

Inspect any other equipment which will be used on the dive as well as any spare equipment that **may** be used during the dive. This would include spare regulators, cylinders, and gages. Also check all protective clothing, lines, tools, flares, and other optional gear. Finally, lay all equipment in a place where it will be out of the way of deck traffic and ready for use.

Diver Preparation 5.2.3 When the diver has completed inspecting and testing his equipment, he reports his readiness to the Diving Supervisor.

At this time the divers should be given a pre-dive review of the dive plan. This review is critical to the success and safety of any diving operation, and is concerned only with the particular dive which is about to begin. All personnel who are directly involved in the dive should be included in the review—and all must understand every detail of the plan.

Items which should be covered include—

- dive objectives
- time 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, particularly, when to abort the dive, what will be done in the event of a lost diver.

When the Diving Supervisor and the divers are all satisfied that the requirements of the operation are fully understood and that the divers are in good health and otherwise ready to proceed, the divers may dress for the dive.

DRESSING 5.2.3.1 Every SCUBA diver must be able to put all of his gear on by himself, although the assistance of a tender or buddy is encouraged. The order of dressing is important as certain items of equipment must be "outside" of all others so that they can be easily dropped in an emergency. The normal order of dressing is as follows—

A. Protective clothing. For ease in putting on a dry suit or a wet-suit, the body and the suit should be sprinkled with talcum powder or corn starch. If the suit is wet from a previous dive, or if the diver is perspiring heavily, a small quantity of liquid detergent or other dishwasing liquid may be used.

B. Boots and hood.

C. Knife (if worn on the ankle or about the waist).

D. Life preserver, with inflation tubes in front and the actuating lanyards exposed and accessible.

E. Knife (if worn on the life preserver).

F. Weight belt.

G. SCUBA. Most easily put on with the aid of a tender who can hold the tanks in position while the diver fastens and adjusts the harness. The SCUBA should be worn centered on the diver's back as high as possible but not so high that his head, when tilted far back, will hit the regulator. All quick release buckles must be so postioned that they can be reached by either hand. All straps must be pulled snug so that the cylinders are held firmly against the body. The ends of the straps must hang free so that 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 1/4 to 1/2 turn.

H. Accessory equipment (watch, compass, and depth gage; snorkel tucked into belt or under a strap; other equipment secure but not in the way).

I. Gloves.

J. Swim Fins.

K. Mask (hold in hand with strap around wrist).

The diver should now report "Ready" to the Diving Supervisor. He is not, however, cleared to dive until a final visual check has been made by the Diving Supervisor and until he has tested the operation of the SCUBA. During this final pre-dive inspection the Diving Supervisor must—

- Verify that all divers have all minimum required equipment (SCUBA, face mask, life preserver, weight belt, knife and scabbard, swim fins).
- Verify that at least one diver per diving team is wearing both a wristwatch and a depth gage.
- Verify that the cylinders have been gaged and that the available volume of air is sufficient for the planned duration of the dive.
- Ensure that all quick-release buckles and fastenings can be reached by either hand and are properly rigged for quick release.

1.
The Life preserver is on and properly tied—**not with a quick-release tie**—and the loose straps are wrapped on themselves. The diver has both depth gage and watch on.

NOTE: The Life preserver should not be tight—but should allow for expansion in the event of inflation.

Figure 5-33 At the start of this sequence the diver has already checked all his equipment and dressed into his wet suit.

- Verify that the weight belt is outside of all other belts, straps and equipment, and is not likely to become pinched under the bottom edge of the cylinders.
- Verify that the life preserver is not constrained, is free to expand, and that all air has been evacuated.
- Check position of the knife to ensure that it will remain with the diver no matter what equipment he may jettison.
- Conduct time check and synchronize watches.
- Ensure that cylinder valve is open and then back-off 1/4 to 1/2 turn.
- With mouthpiece or full face mask in place, have diver breathe in and out for 30 seconds. While doing this, he should be alert for any impurities in the air or for any unusual physiological reactions.
- Give the breathing tube(s) and mouthpiece a final check; make sure that none of the connections have been pulled open during the process of dressing.
- Check the air reserve pull-rod, to make sure that it has not been bent and is free to move.
- Check that the air reserve mechanism is in the closed position (the pull rod in the "up" position).
- Conduct brief final review of the dive plan.
- Ensure that the divers are physically and mentally ready to enter the water.
- Verify that the proper diving signals are being displayed and that personnel and equipment are ready to give proper visual, sound or radio signals to warn off other vessels.

The diver is now ready to enter the water but not yet ready to dive as his SCUBA must be given another brief inspection once he is in the water.

2.
The weight belt, properly weight balanced, is next and tied with a quick-release tie or clasp.

NOTE: It is **not** generally recommended that the diver knife be worn on the weight belt as is shown in this sequence.

3-4.
To prevent face mask fogging, saliva is normally rubbed over the inner surface of the lens and rinsed in water.

5.
The diver has his hood on and with the aid of a tender is preparing to put the SCUBA on. Shoulder straps have been adjusted and tied for quick-release.

6.
With the tender supporting the weight of the tanks the diver slips into the shoulder straps.

Generally the tender will have to assist the diver with the second shoulder strap while still supporting the weight of the cylinders.

9.
Once the straps are in position and not twisted, the tender will aid in adjusting the SCUBA to the proper position on the diver's back.

10.

11.
The tender then slips the hoses and mouthpiece over the diver's head.

12.
The diver will make final strap adjustments and tie the chest straps, passing them **under** the life preserver. Note the diver's stance—just forward enough to balance the weight of the equipment but not so far as to support the weight of the SCUBA.

13.
While the tenders make a final check on the equipment the diver will check the regulator function with a number of deep breaths.

14.
The face mask is then placed in position. Note the tender assisting the diver in maintaining his balance.

15.
The diver now puts his swim fins on, supporting himself on a stable support, both tenders close at hand.

16.
After putting his gloves on, the diver is ready for a final check just prior to entering the water where he will undergo a final surface check out of his equipment.

WATER ENTRY 5.2.3.2 There are several methods of water entry, with the choice usually determined by the nature of the diving platform. Whenever possible, entry should be made by ladder. This is particularly true 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 them from hitting the back of the head.
- hold the mask in place with the fingers and the mouthpiece in place with the heel of the hand.

The front jump, or step-in, is the most frequently used method and is best used from a stable platform or vessel which is not easily disturbed by the diver's movements. To make the entry, the diver should not actually "jump" into the water but simply take a large step out from the platform, keeping his legs in an open stride. He should try to enter the water with a slightly-forward tilt of the upper body so that the force of entry will not drive his tank up to hit the back of his head.

Figure 5-34 SCUBA entry techniques—Front jump or step-in. On edge of platform, one hand holding face mask, the other holding his tanks, the diver takes a long step forward keeping his legs astride.

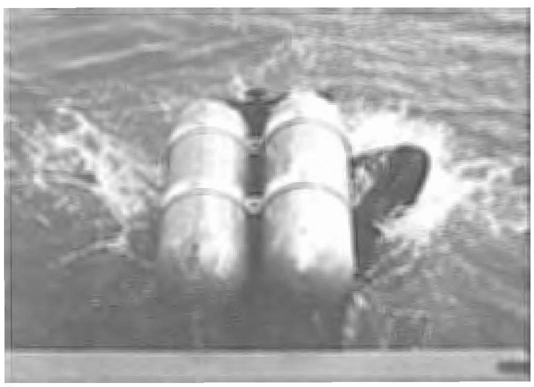
1.
Tender assists diver in taking a seated position. Tender stands clear, diver holds his mask and bottles.

2.
And rolls into water.

Figure 5-35 SCUBA entry techniques—Side roll

1.
Diver sits on edge of platform with a slight forward lean to offset the weight of his cylinders

2.
Holding his mask and cylinders, the diver leans forward keeping his legs tucked into his body.



3.
At the instant of entry; Note the diver's hand maintaining its hold on the SCUBA.

Figure 5-36 SCUBA entry techniques—Front roll

Figure 5-37 Scuba entry techniques—Rear step-in—the diver descends the ladder and steps backward pushing himself away with his feet.

Figure 5-38 SCUBA entry techniques—Rear roll—the diver sits on the gunwale facing inboard—
and holding his mask with one hand rolls backward.

The **rear jump or step-in** is normally used when the ladder does not quite extend to the water. The diver, facing the ladder, steps backward pushing away from the ladder with his feet.

The **rear roll** is the normal method for entering the water from a small boat. A fully-outfitted diver, standing on the edge of a boat, would unnecessarily upset the stability of the craft and the diver himself would be in danger of falling either into the boat, or, unprepared, into the water. To execute a rear roll, the diver sits on the gunwale of the boat, facing inboard. With chin on chest and one hand holding his mask and mouthpiece in place (just as in all other methods of entry), he rolls backward, essentially moving through a full backward somersault.

If working from the beach, the diver will make a choice of entry depending upon the condition of the surf and the slope of the bottom. If the water is calm and the slope gradual, the diver can walk out, carrying his swim fins until he reaches water deep enough for swimming. If moderate to high surf is running (but not high enough to cause postponement of the operation), the diver, wearing his swim fins, should walk backwards into the waves, until he has enough depth for swimming. He should gradually settle into the waves as they break around him.

If normal breathing is not soon restored, he must take it to be a symptom of developing danger, and immediately break off the operation, signal his buddy, and, together, head for the surface.

Some divers, knowing that they have a finite air supply which must govern the length of the dive, 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. **Breath-holding and skip-breathing are dangerous** and frequently lead to shallow-water blackout. Divers must not use these techniques in an effort to increase bottom time (See Section 3.4.7, Chapter Three).

Every diver will note some increased resistance to breathing caused by the design of his equipment. For normal diving, the level of resistance should not change until the primary air supply has been almost depleted. A marked increase in breathing resistance is the signal to the diver to activate his air reserve and to immediately begin his ascent. A diver can check on the status of his air supply by taking a sudden, deep breath. If there is a marked pinching off of the air, the supply is approaching exhaustion.

MASK CLEARING 5.3.3.2 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 up to a point where it must be removed. Also, on occasion, a mask may become dislodged and flooded.

To clear a flooded mask not equipped with a purge valve, the diver should roll on his 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.

For a mask with a purge valve, the diver merely tilts his head so that the accumulated water covers the valve, presses the mask against his face, and then exhales firmly and steadily through his nose. The increased pressure in the mask will force the water through the valve. Occasionally, more than one exhalation will be required.

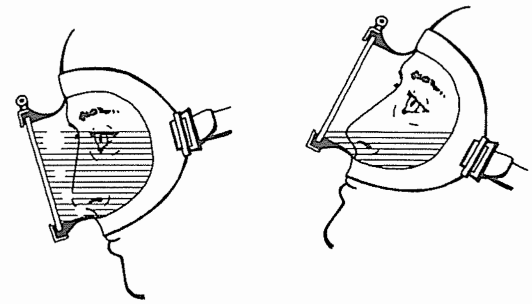


Figure 5-41 To clear a flooded face mask, push gently on the upper portion of the mask and exhale through the nose into the mask. As water is forced out, tilt the head backward until the mask is clear.

HOSE AND MOUTHPIECE CLEARING 5.3.3.3

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 too serious a problem since the hose (carrying air at medium pressure) will not flood and the mouthpiece can quickly be cleared by depressing the purge button as the mouthpiece is being replaced.

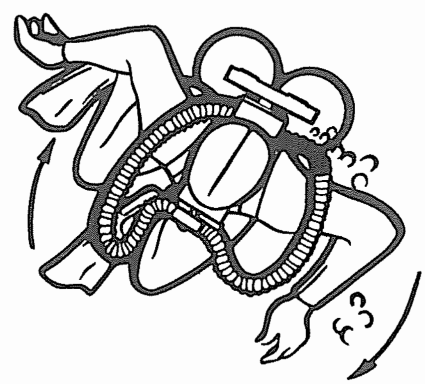


Figure 5-42 To clear a double hose SCUBA, roll to the left side, pinch off the intake hose and exhale—resume normal position and continue normal breathing. The procedure may have to be repeated to completely clear a flooded hose.

To clear a double hose SCUBA which has flooded because of a lost mouthpiece, the diver, swimming in a horizontal position, should roll over on his left side. He should then grasp the mouthpiece, squeeze off the inhalation hose (right hose) and blow into the mouthpiece. This will force any water trapped in the exhaust out through the regulator's exhaust ports. He should then release the inhalation hose and take a shallow breath with caution. There may still be water trapped in the mouthpiece and, if so, the diver should blow through it once more and resume normal breathing.

UNDERWATER SWIMMING TECHNIQUE 5.3.3.4
For underwater swimming all propulsion comes from the action of the legs. The hands are used only for maneuvering. The leg kick should be through a large, easy arc with the main thrust coming from the hips. The knees and ankles should be relaxed. The rhythm of the kick should be maintained at a level that will not unduly tire the legs or bring on muscle cramps.

THE BUDDY SYSTEM 5.3.3.5 The greatest single safety factor in Navy SCUBA operations is the buddy system. Divers, operating in pairs, are responsible for both the assigned task and each other's safety. The basic rules for buddy diving are—

A. Always maintain contact with the buddy. In good visibility, keep him in sight. In poor visibility, use a buddy line.

B. Know the meaning of all hand and line signals.

C. If a signal is given, it should immediately be acknowledged. Failure of a buddy to respond to a signal must be considered an emergency.

D. Monitor the actions and apparent condition of the buddy. Know the symptoms of diving ailments. If at any time the buddy appears to be in distress or to be acting in an abnormal manner, an immediate determination of the cause should be made and appropriate action taken.

E. Never leave a buddy unless he 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.

F. Establish a "lost diver" plan for any dive. If buddy contact is broken, follow the plan.

G. If one member of a buddy pair aborts a dive, for whatever reason, the other member will also abort and both will surface.

H. Know the proper method of "buddy breathing."

DIVER COMMUNICATIONS 5.3.3.6 The primary form of underwater communication between divers is by hand signal; primary communication between the surface and a diver is accomplished through linepull signals. If divers are operating under conditions of low visibility, the buddy pairs will at times be forced to communicate with line-pull signals on the buddy line.

Figure 5-43 presents the U.S. Navy approved hand signals. Line-pull signals are discussed in Chapter Six. Navy divers will not use any signals which have not been approved for Navy diving use. Under certain conditions special hand signals applicable to a specific mission may be devised and approved by the Diving Supervisor.

Hand signals and line-pull signals should be delivered in a forceful, exaggerated manner so that there can be no ambiguity about the signal and so that it is obvious that a signal is in fact being given. Every signal must be acknowledged.

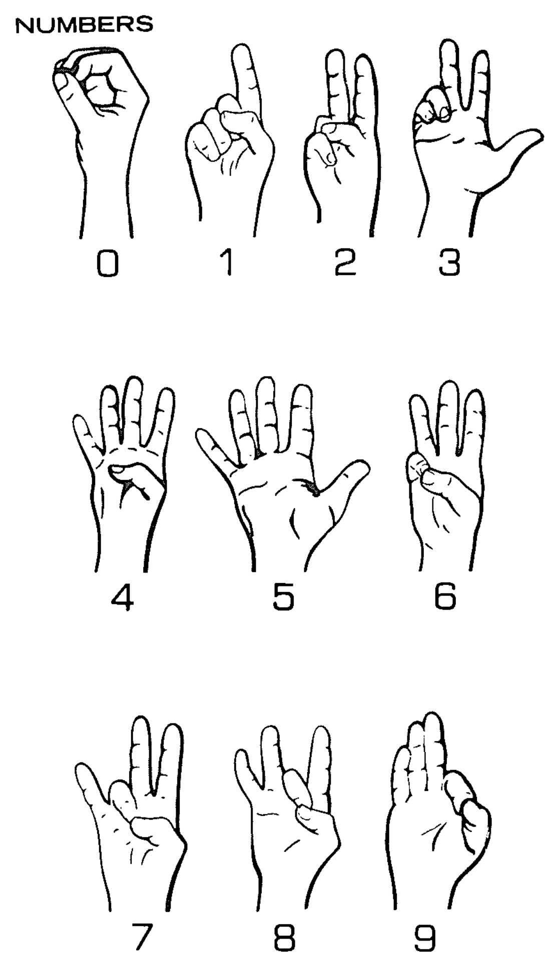
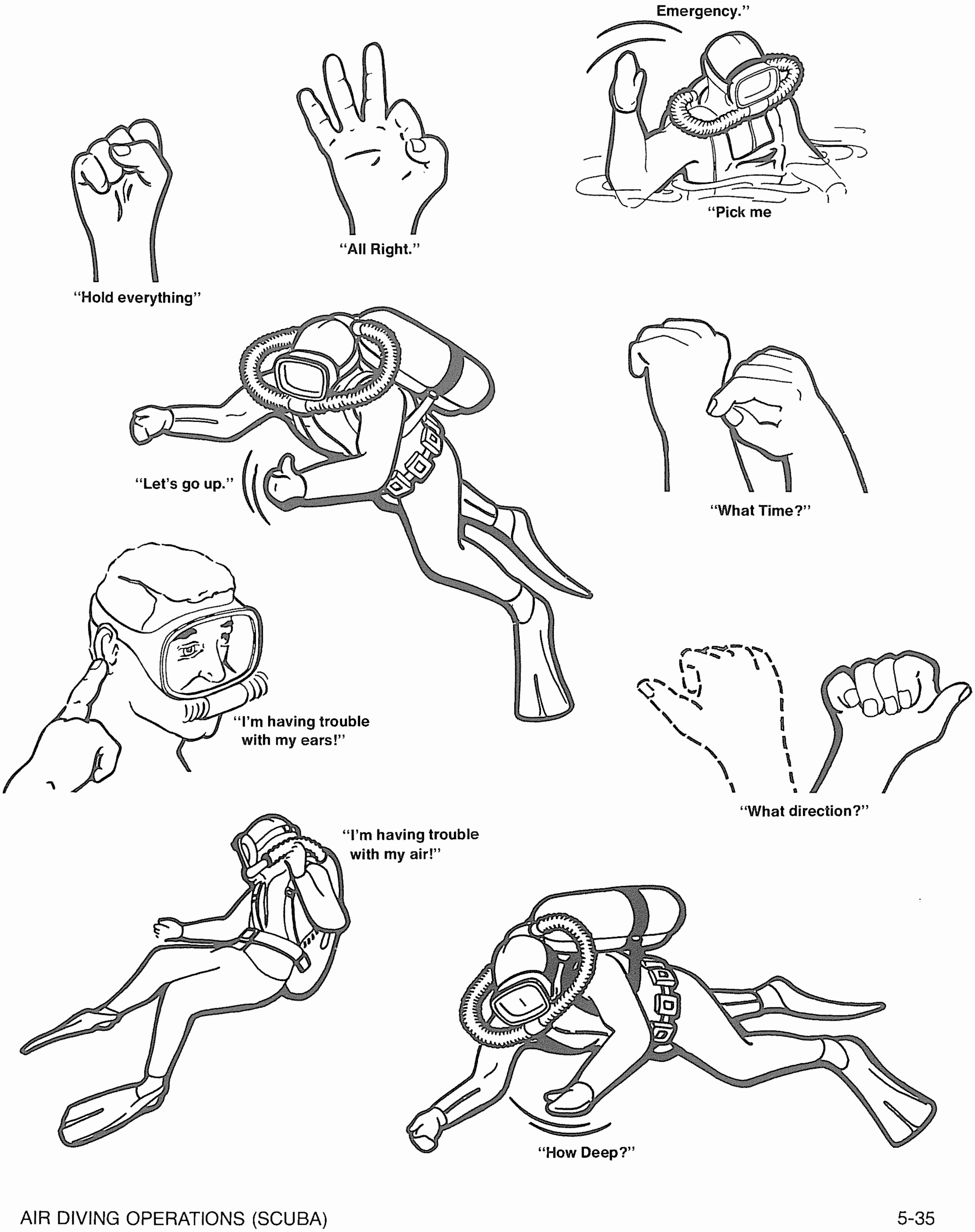


Figure 5-43 Scuba Hand Signals


Emergency."
"Pick me
"All Right."
"Hold everything"
"Let's go up."
"What Time?"
"I'm having trouble
with my ears!"
"What direction?"
"I'm having trouble
with my air!"
"How Deep?"

BUDDY BREATHING 5.3.3.7 If a diver runs out of air or his SCUBA malfunctions, he can obtain air from his buddy's SCUBA on a sharing basis. Buddy breathing is strictly an emergency procedure, which must be practiced in advance of need so that each diver will be thoroughly familiar with the procedure.

The steps to be followed in buddy breathing are—

A. Remain calm, and signal the problem to the buddy by pointing at your mouthpiece.

B. Do **not** grab for the buddy's mouthpiece. The diver places his hand on the hand which the buddy is using to hold the mouthpiece. The buddy and the diver should hold on to each other by grasping a strap or the free arm.

C. The buddy must make the first move by taking the mouthpiece from his mouth after taking a breath and passing it to the other diver. The other diver will then guide it to his mouth. Both divers will maintain direct hand contact on the mouthpiece.

D. The mouthpiece may have flooded during the transfer. In this case it must be cleared either by use of the purge button (if single hose) or by exhaling before a breath can be taken.

E. The diver should take two full breaths, (exercising caution in the event that all of the water has not been purged) and hand the mouthpiece back to the buddy. The buddy should then take two breaths, and the cycle is repeated.

F. The diver taking the breaths may become more buoyant than the other. The divers must be careful not to drift away from each other. If using a double-hose regulator the mouthpiece should be kept slightly higher than the regulator so that free-flowing air will keep the mouthpiece clear.

G. 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.

H. During ascent the diver without the mouthpiece must exhale slowly to offset the effect of decreasing pressure on their lungs.

Figure 5-44 Divers practicing the proper buddy-breathing procedure.

TENDING 5.3.3.8 When a diver is being tended by either a line from the surface or a buddy line, several basic considerations apply—

- lines should be kept free of slack.
- line signals must be given in accordance with the procedures given in Section 6.3.2 of Chapter Six.
- any signals via the line must be immediately acknowledged by returning the same signal.
- the tender should signal the diver with a single pull every two or three minutes to determine if the diver is "all right." A return signal of one pull from the diver will communicate that he is all right.
- the diver must be particularly aware of the possibilities for snagging his line or for becoming entangled.

If a surface-line is not being used, the tender must keep track of the general location of the divers by observing the bubble tracks or the witness float.

WORKING WITH TOOLS 5.3.3.9 The near-neutral buoyancy of a SCUBA diver poses certain problems when working with tools. The diver is virtually unable to bring any leverage to bear. When he tries to apply force to a wrench, for example, he will push himself away from the wrench and very little force will be applied to the work. When using any tool which requires such leverage or force (including pneumatic power tools), the diver should try to brace himself in some way with his feet, a free hand, or a shoulder. 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 will permit most of the effort to be transmitted to the work.

Any tools to be used should be organized in advance, and the diver should carry as few items with him 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 WORK PROCEDURES MANUAL (NAVSHIPS 0994-007-8010).

ADAPTING TO UNDERWATER CONDITIONS 5.3.3.10 Through careful and thorough planning, the divers will be prepared for the underwater conditions at the diving site and will have been provided, as necessary, with appropriate auxiliary equipment, protective clothing, and tools. Adaptation to certain conditions, however, cannot be facilitated by accessory gear and the diver will have to employ particular operational techniques to offset the effects of these conditions.

For example—

- —stay two or three feet above a muddy bottom, use a restricted kick and avoid stirring up the mud. A diver should position himself so that the current will carry any clouds of mud away from the work site.
- —over a coral or rocky bottom, be careful to avoid cuts and abrasions.
- —avoid abrupt changes of depth.
- —do not make sight-seeing excursions to explore "interesting" sites away from the dive site unless such excursions have been included in the dive plan.
- —be aware of the peculiar properties of light underwater. Depth perception is altered on a basis of 3 to 4 (an object that seems to be three feet away is actually four feet away), and objects tend to appear larger than they really 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 generated during the job.
- —stay clear of lines or wires which are under stress.

Ascent (Normal) 5.3.4 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 must start together for the surface.

For a normal ascent, from a dive with no decompression requirements, the divers will breathe steadily and naturally, and ascend to the surface at a rate of 60 feet per minute. The divers must never hold their breath during ascent, because of the danger of an air embolism.

If decompression is required, the divers will ascend according to the appropriate decompression schedule.

While ascending, keep a watch overhead for objects —especially those which may be floating on the surface. A good practice is to spiral slowly while rising to provide a full 360 degree scan. The diver should keep an arm extended over his head to prevent striking his head on any unseen object.

Ascent (Emergency) 5.3.5 If a diver is suddenly without air or if his SCUBA is entangled and his buddy cannot be quickly reached, he must make an emergency free ascent. The proper procedure is—

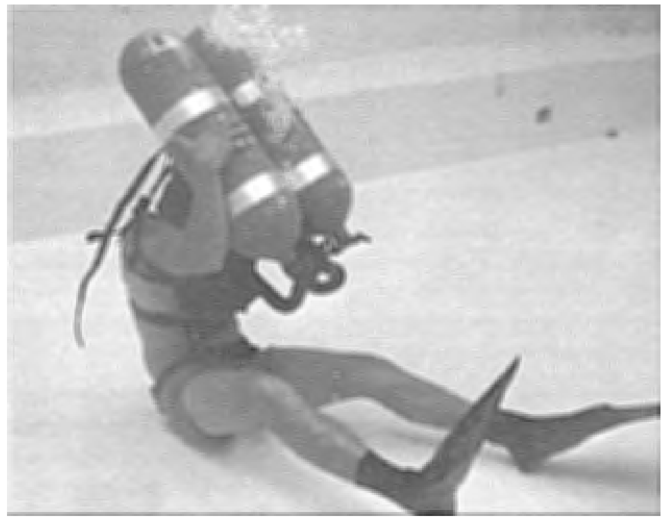
A. Drop any tools or objects being carried by hand.

B. Ditch the weight belt.

C. If the SCUBA has become entangled and must be ditched, 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. Exercise care that the hoses do not tangle on the neck. Some single hose units are delivered with neck straps. These tend to complicate the ditching procedure and should not be used.

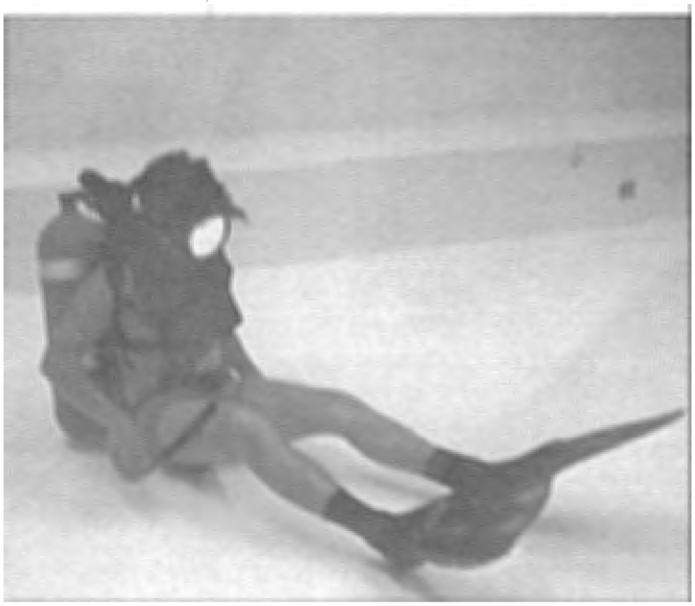
D. In most instances the emergency ascent is necessitated by a loss of air. After dropping all heavy objects and the weight belt, actuate the life preserver and surface immediately. Do not ditch the SCUBA unless it is absolutely necessary. During the ascent, the pressure differential between the air in the cylinders and the air in the medium pressure chamber of the regulator will increase. This may permit some of the air remaining in the cylinders to be supplied to the diver. If a diver is unconscious and cannot help himself to the surface, and his buddy anticipates difficulty in trying to carry him to the surface, the buddy should release the diver's weight belt and activate his life preserver to lighten the load. Under no conditions, however, should the buddy lose direct and secure hand contact with the diver.

E. During ascent, exhale continuously. Let the expanding air in the lungs freely escape.



B Holding the manifold with one hand the diver pulls the SCUBA up and over his head while guiding the tanks with the other hand.

C Once over his head the diver shifts his grip to the center of the tanks and lowers then to between his legs. Note that the diver has not released the mouthpiece and continues to breathe with the SCUBA.



A In a seated position the diver pulls the quick-release straps on the SCUBA

D The diver continues to hold the SCUBA while he removes his weight belt and places it on the SCUBA—between the cylinders. Up to this point the diver retained the weight belt to control his buoyancy, but now with the weights used to hold the SCUBA down the diver will have to work at staying on the bottom.

Figure 5-45 Ditching the SCUBA

On the surface the diver can rest while waiting to be be picked up. He can orally inflate his life vest for support, or he can keep his mask on and use the snorkel for breathing while floating face down and relaxed in the water. However, he must periodically check for any nearby surface traffic.

As the divers break the surface, the tender and other personnel in the support craft must keep them constantly in sight and be particularly alert for any signals or 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 not over until all divers are safely aboard.

Getting into the boat will usually be easier if the diver takes off his weight belt and SCUBA and hands them to the tender. If the boat has a ladder, he should also take off his swim fins. Without a ladder, the swim fins will help to give him an extra push to get aboard. A small boat may be boarded over the side or over the stern depending upon the type of craft and the surface weather conditions. As each diver comes aboard a small boat or a raft, other personnel in the boat should remain seated.

POST-DIVE PROCEDURES 5.4

Physiological problems may not be evident until some time after a dive. The diver and all other members of the diving team must constantly be alert for the possibility of such problems as decompression sickness and embolism. Injuries sustained during a dive—such as cuts or animal bites—may not be noticed at first because of shock or the numbing effect of cold water. For these reasons diving personnel should remain under the observation of the Diving Supervisor for as long as possible after a dive.

If satisfied with his apparent physical condition, the diver's first responsibility after the dive is to check his equipment for damage and get it out of the way of the on-deck activity.

The Diving Supervisor should de-brief each returning diver as soon as practical while the experience of the dive is still fresh in the diver's mind. The Diving Supervisor should determine if the assigned tasks were completed, if any problems were encountered, if any changes to the over-all dive plan are indicated, and if the divers have any suggestions for the next team.

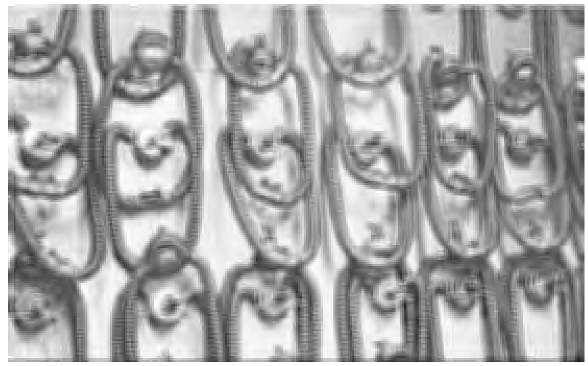
Post-Dive Maintenance and Stowage 5.4.1 Each diver is responsible for the immediate post-dive maintenance and proper disposition of the equipment he used during the dive. The following procedures should be followed—

A. Turn off the cylinder on/off valve and open the air reserve valve—even if the tank has only been partially used. This will serve as a warning that the tank has been used and must be checked and refilled. It is also a good practice to place it in a specially designated area to avoid any possible mix-up.

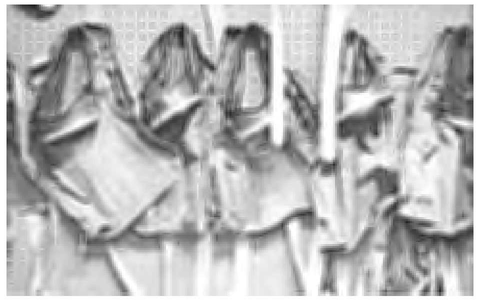
B. Bleed the regulator by inhaling through the mouthpiece, or pressing the purge button, and remove the regulator.

C. Be sure that the protective cone is clear of water or dirt, check the "o" ring, and secure the cone in place over the regulator inlet. This will keep foreign particles out of the regulator and also permit submerging the regulator in

A Cylinders should be securely stowed and pressure should be checked at regular intervals.



B Regulators should be stowed so that they will not be subjected to damage and hoses will not be stretched.



C Masks and life preservers properly stowed for complete drying.

D Swim fins hung in pairs in an orderly manner. Note use of wide hanging brackets.

E Wet suits should be thoroughly washed in fresh water and hung on wide, contoured hangers.

Figure 5-47 Proper stowage of SCUBA equipment is essential for safety and long service life.

fresh water for cleaning without permitting water to enter the first stage of the regulator.

D. If the regulator—or any other equipment—has been damaged, it should be tagged "damaged" and separated from the rest of the equipment. Damaged equipment should be repaired, inspected, and tested as soon as possible. Irreparable equipment must be destroyed and discarded.

E. Wash all equipment with fresh water and be sure to remove all traces of salt. The salt will not only speed corrosion of the materials, but may also plug up vent holes in the regulator and the depth gage. All parts of the equipment which must be free to move—such as diaphrams and check valves, quick-release buckles, the knife in the scabbard, and CO_2 actuators in life vests should be carefully checked for corrosion, salt, or dirt build-up. The mouthpiece should be rinsed several times in fresh water and an oral disinfectant. Periodically, the breathing hoses of a double-hose regulator should be unclamped and removed from the regulator and mouthpiece and cleaned internally.

F. When all equipment has been washed and rinsed, it should be hung up to dry and then placed in appropriate stowage. Regulators should be stowed separately and never left mounted on cylinders. When dry, wet suits should be dusted with talcum and carefully folded or hung. The suits should never be hung from a hook or a wire hanger since they will stretch out of shape or be torn. Masks, depth gages, life vests and any other equipment which can be damaged or scuffed by rough handling should be individually stored and never dumped collectively in a box or drawer. Batteries should be removed from lights, tested, and stored separately. All lines should be dried, coiled and properly stowed.

H. A fully-charged cylinder may be stored for months without harm. The quality of the air will not deteriorate. However, it is a good practice to change the air in a cylinder if it has been in storage for over a year. The pressure of each cylinder in storage should be gaged weekly. If a marked drop in pressure is noted, the cylinder should be withdrawn and checked.

FIELD MAINTENANCE OF SCUBA EQUIPMENT 5.5

Complete maintenance of SCUBA regulators, valving, tanks and accessory equipment should only be performed by trained personnel in properly equipped facilities. Specific instructions for such maintenance are found in the technical manuals provided by the equipment manufacturers.

The diver, however, will frequently find it necessary to perform simple field maintenance and repair. Such first-line care will do much to ensure the continued safe and efficient operation of the equipment.

Each diving facility should assemble or have access to a basic "Field Repair and Maintenance Kit." Such a kit can be tailored to individual requirements and local practices. A typical, reasonably complete kit is described in Table 5-5.

Practical Suggestions for Field Maintenance and Repair by Divers 5.5.1—

Masks—If a mask strap is broken or separated due to a lost buckle (and a new strap is not available), a temporary repair can be accomplished by connecting and whipping the strap ends with waxed linen thread or dental floss.

Swim Fins—Swim fin straps can be repaired in much the same manner as broken mask straps. If sewing with thread or dental floss is required to repair a strap or hole in the fin, the hard rubber is more easily penetrated if the needle is heated using paraffin candles, or if the holes are pre-punched with a heated awl or ice-pick.

Snorkels—Loose mouthpieces or holes in snorkels can be patched with plastic adhesive tape.

Straps and Weight-Belt—Ends on straps and weight-belts which are made of nylon can be kept from fraying or unravelling by melting them. Nylon line ends can be burned in a similar manner to prevent unravelling. Holes in weight belts can be smoothed by light melting.

Wet-Suit Repair—Tears in wet suits may be repaired using commercial repair kits or tire repair kits. If using glue, instructions on the container should be carefully followed. Torn edges should be trimmed smooth with a knife or razor blade before sewing or gluing. Repair is best accomplished by applying glue and waiting until it is dry to the touch. Edges should be pressed together or clamped if possible. Sewing gives additional strength. Wet suit zippers and seams should always be both glued and sewn for maximum bonding strength.

ALL REPAIR AND MAINTENANCE SHOULD BE FOLLOWED BY A THOROUGH INSPECTION AND TESTING OF THE EQUIPMENT TO ENSURE ITS FULL OPERABILITY AND SAFETY. **IF THERE IS ANY QUESTION ABOUT A PARTICULAR PIECE OF EQUIPMENT, DO NOT DIVE WITH IT UNDER ANY CIRCUMSTANCE.**

RECORD KEEPING AND REPORTS 5.6

The subject of record keeping and reports is covered in Appendix B. A common tendency, in dealing with records and reports, is to postpone the effort to the last possible minute. Sometimes this is merely a manifestation of human nature; sometimes there may seem to be plausible reasons for the delay. However, all reasons notwithstanding, reports must be filed promptly and records must be maintained on a priority basis.

TABLE 5-5
FIELD MAINTENANCE AND REPAIR KIT

TOOLS

Crescent Wrenches
- 1 size 16″
- 1 size 8″
- 1 size 4″

Screw Drivers
- flat 5/16″ with 6″ shaft
- flat 1/4″ with 6″ shaft
- phillips No. 2 with 6″ shaft

Files
- 1—rat tail, medium coarseness
- 1—flat, medium coarseness

Awl or ice-pick—for removing O'rings or punching holes in belts or straps

Single-Edge Razor Blades pack—for trimming wet suit mat.

Pliers—assorted

Sail Needles—small, both straight and curved

Sailor's Palm

Nylon Strapping Crimping Tool

Pen Knife

Claw Hammer—medium weight

Wire Brush—long handle

Vice-Grip Pliers

Sharpening Stone

Wire-Cutters—medium size

Hacksaw and blades

Tool container—either plastic box or canvas bag

Spares

O -rings—necessary sizes

Mask straps

Buckles

Purge Valves and components

Quick-Release "D" rings

SCUBA mouthpieces

SCUBA hoses—for double hose rigs

Snorkle mouthpieces

Exhaust vents—single hose rigs

Weights

Spare Masks

Spare Swim Fins

Spare Weight Belts

Supplies

Spare wet suit material (one yard)

Nylon or brass wet suit zippers

1/8″ nylon strapping and nylon clips

Waxed linen, nylon, or dacron thread (dental floss is also used)

Adhesive plastic tape (3/4″)

Spray can of silicone

Spray can of silicone based grease

Spray can of light oil

Miscellaneous nuts, bolts, washers, etc.

Paraffin candles—for burning nylon ends, heating tip of awl to penetrate heavy rubber materials such as swim fins

Masking tape (1/2″)

Matches

Neoprene cement for wet suits

Wire—bailing or leader type

Waterproof felt pens

Contact cement

Epoxy glue

Manila line—(1/4″)

Talcum powder—or corn starch

Liquid detergent

Towel—(paper towels)

Figure 6-4 Navy Standard Diving Helmet

air supply from the surface should fall below ambient pressure at depth. If this check valve were not included in the system, and the air supply pressure were to drop, the air in the suit would quickly be forced back up the supply hose by the outside water pressure. The result could be serious or even fatal injury to the diver from the effects of squeeze (described in Chapter Three). There are two types of non-return valves available: a spring-and-stem valve and a cartridge valve with an "O" ring seal. Both types have a male thread at one end and a female submarine thread (17 threads/inch) at the other. The valve is screwed directly onto the air inlet gooseneck. To insure that the valve is not installed backwards, the screw threads on the gooseneck are male submarine threads, to match the female threads on the helmet-end of the valve. A non-return valve is a mandatory component of any surface-supplied diving outfit.

The exhaust valve is located between and slightly below the right port and the faceplate and is fitted with an escape channel which directs the flow of exhausted air toward the rear of the helmet. This keeps the exhaust bubbles from rising in front of the diver, and interfering with his vision.

The exhaust valve serves to control the amount of air in the diving outfit. This control serves two purposes: to protect the diver from squeeze by maintaining adequate air pressure in the suit and to permit the diver to vary his buoyancy by adjusting the amount of air in

the suit. The exhaust valve is designed to open slightly whenever the air pressure in the helmet exceeds the outside water pressure by more than 0.5 psi. The rate at which the air will be exhausted is controlled by the external valve wheel which is manipulated by the diver. By slowing the rate of exhaust, he will permit more air to build up in his suit and increase his buoyancy. To reduce buoyancy, the diver will open the valve and increase the rate of exhaust.

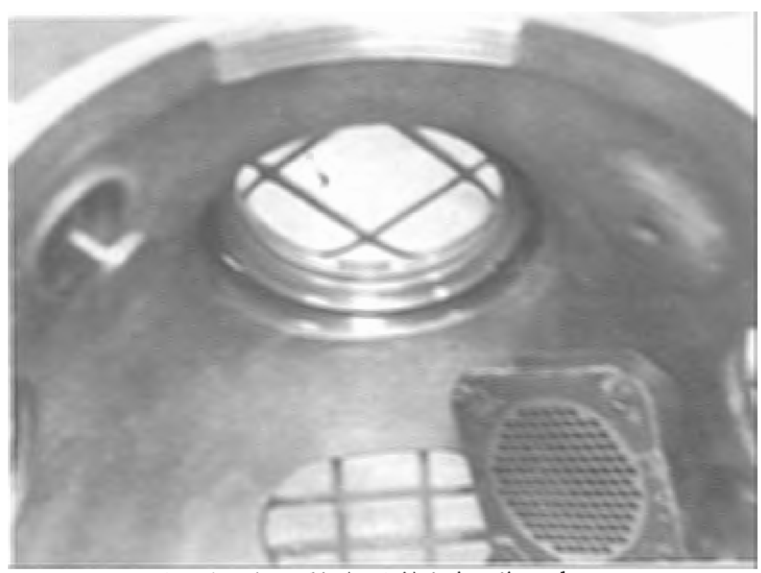


Figure 6-5 Interior view of helmet. Note location of reproducer and chin button.

Should a pressure differential of more than 2 psi occur, the valve will open fully so that air will be exhausted at a maximum rate. This secondary relief feature helps to guard against the possibility of blow-up which can occur when the air pressure in the suit builds to a point where excessive buoyancy is achieved and an uncontrolled ascent results. Should this relief feature fail, the diver may fully open the valve by depressing the chin button inside the helmet. The chin button connects directly to the stem disc and allows it to be mechanically opened or closed by pressing on the button with the chin or pulling it closed with the lips.

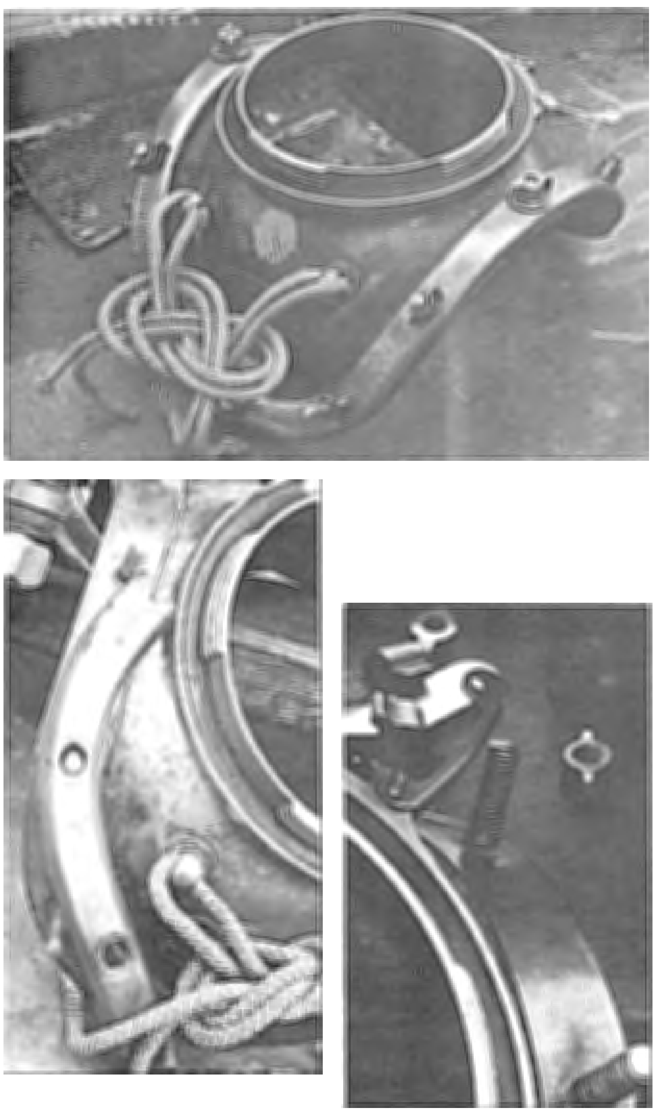


Figure 6-6 Breastplate Assembly

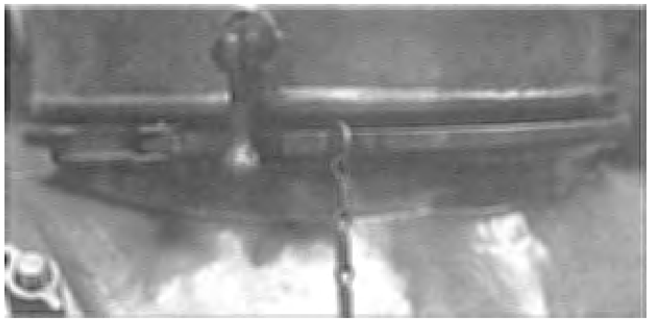
The spitcock is on the left side of the helmet in the same relative position as the exhaust valve. This is a simple, lever-operated valve which, when used in balance with the exhaust valve, allows the diver to make fine adjustments in his buoyancy. It also provides a means for the diver to intentionally draw some water into his helmet for use in clearing a fogged faceplate, and it serves as an auxiliary exhaust valve when the diver is working on his right side.

The breastplate is designed to distribute the weight of the helmet over the diver's shoulders and to provide the means to effect a water-tight seal between the helmet and the diving dress.

The breastplate and the helmet are joined at the neck by an interrupted screw joint. A leather gasket, fitted into the gasket ring on the breastplate, keeps the joint under pressure and water-tight. The dumbbell safety lock on the helmet fits into a matching recess on the breastplate gasket ring and keeps the helmet from shifting, breaking the seal, and possibly coming off entirely. A safety latch on the breastplate prevents the locking ball of the dumbbell from falling out of the recess, and this latch, in turn, is held in place with a brass cotter pin.

Twelve equally-spaced studs soldered into the stud collar serve to seal the breastplate to the diving dress. The studs fit through matching holes in the heavy rubber gasket which forms the collar of the diving dress. Four copper breastplate straps (sometimes called brales) fit over both the collar gasket and the studs; a water-tight seal is ensured by the use of wingnuts, with copper washers and special flanged wingnuts at the joints between the straps. The straps are custom-made for each breastplate and cannot be interchanged with each other or with another breastplate. For this reason, each brale is marked for "front" or "back" and is serialized to match the breastplate.

One long stud (the bastard stud) on the left lower front of the breastplate supports the air control valve (part of the hose group), and two padeyes on the front of the breastplate are used in securing the air hose and the life-line/amplifier cable.



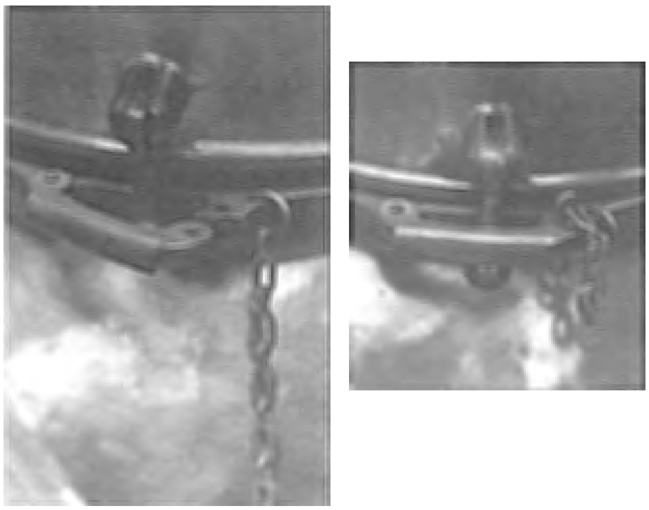


Figure 6-7 Helmet/Breastplate Locking Assembly

THE DIVING DRESS GROUP 6.1.1.2 The basic diving dress is constructed of vulcanized natural rubber, friction calender coated between an outer cotton twill layer and an inner cotton drill layer, with heavy chaffing patches cemented to the areas of highest wear—the elbows, knees, crotch and toes. This dress encloses the entire body (except for the head and hands) in a tough, waterproof cover.

Figure 6-8 Deep-Sea Diving Dress

A heavy rubber gasket collar at the neck forms the junction with the breastplate, and a fabric bib is fitted around the inside of the neck opening just below the gasket. This bib, coming well up around the diver's neck, serves to trap any water that might leak in through the valves in the helmet. A molded rubber bead on the inner edge of the collar prevents it from tearing.

Figure 6-9 Diver/Tender Gloves and Wrist Straps

The dress is sealed at the wrists by tight-fitting rubber cuffs, or alternatively, a pair of diver/tender gloves may be worn or permanently attached to the diving dress. These are three-fingered rubber gloves, molded into the position of a semi-closed hand, which offer good protection from cold and injury. (Instructions for sealing either rubber cuffs or diver/tender gloves to the diving dress are presented at the end of this chapter.) When gloves are worn as a separate item of dress, they are temporarily secured to the cuffs by wrist straps. These straps are also used in adjusting the length of the sleeve.

A set of flaps and lacings is provided along the rear of each leg. When snugly laced, they serve to keep air out of the lower legs, thus reducing the tendency to up-end the diver.

Special woven thermal underwear is worn under the diving dress for protection from the cold and from skin irritation caused by the fabric of the dress. The number of sets worn depends upon the water temperature and the bottom time of the dive, but at least one set must be worn on all dives. The underwear is available in undershirts, drawers, socks and gloves. The standard sizes of both the diving dress and diving underwear are shown in Tables 6-1. Sizes of dresses are designated by one, two or three grommets located on the rear of the bib.

TABLE 6-1

Sizes of U. S. Navy Deep-Sea Diving Dress

Size 1—Small—5′7″ to 5′9″—one grommet

Size 2—Medium—5′9″ to 5′11″—two grommets

Size 3—Large—5′11″ to 6′2″—three grommets

Sizes of Diver's Underwear

Drawers—available in sizes 32, 34, 36, 38, 40, 42 and 44

Shirts—available in sizes 32, 34, 36, 38, 40, 42 and 44

Gloves—medium

Socks—medium

A padded helmet cushion (or other similar padding provided by towels or heavy wool socks) is worn under the dress on the diver's shoulders. This buffers the weight of the helmet and breastplate while the diver is out of the water and reduces chaffing at the shoulders. Most divers prefer not to wear the standard helmet cushion because of the possibility of the cushion sliding backwards and choking the diver.

Chaffing pants, in the form of light canvas trousers, are worn over the diving dress to provide additional protection against wear. The pants have shoulder straps, a waist draw-string and leg lacings, all of which combine to hold the pants in place and to keep bulk to a minimum.

A weighted belt is worn to overcome the essentially positive buoyancy of a deep-sea diving dress. The standard Navy belt is made of double-backed, waterproofed leather and weighs approximately 84 pounds. The weight's provided by individual 7.5 pound lead units.

The belt is worn around the diver's waist as low as possible. It buckles in back and hangs from two sturdy leather shoulder straps which cross each other both in front, below the front stud, and in back, below

Figure 6-10 Chaffing Pants

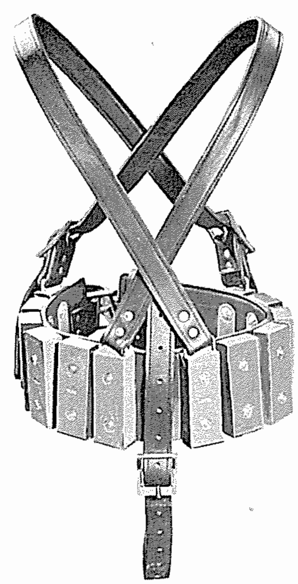


Figure 6-11 Weighted Belt

the back strap, to keep the belt from shifting. A third strap, the jockstrap, prevents the helmet from rising off the diver's shoulders, which would happen if the dress were permitted to elongate upon inflation.

Diving shoes, give protection and add weight to the diver's feet and help the weighted belt to offset the positive buoyancy of the diving dress. Also, by adding weight low on the body, they greatly increase the diver's underwater stability. The shoes are made of leather or canvas uppers with a hardwood inner sole, a lead lower sole, and a cast-bronze toe guard. They are held on the foot by straps and laces, and come in two sizes: standard, which weigh about 35 pounds per pair, and lightweight, which weigh 20 pounds per pair. The difference is provided by the material in the weighted sole: lead in the standard shoe, and brass in the lightweight shoe.

The standard Navy issue diver's knife could more properly be called an all-purpose tool. Made of durable steel with one cutting edge and one saw edge, the knife can be used for cutting, sawing, prying and hacking on wood, lines and ropes, and sheet metal. The handle is constructed of hardwood, and a special cylindrical brass sheath is provided into which the knife can be screwed

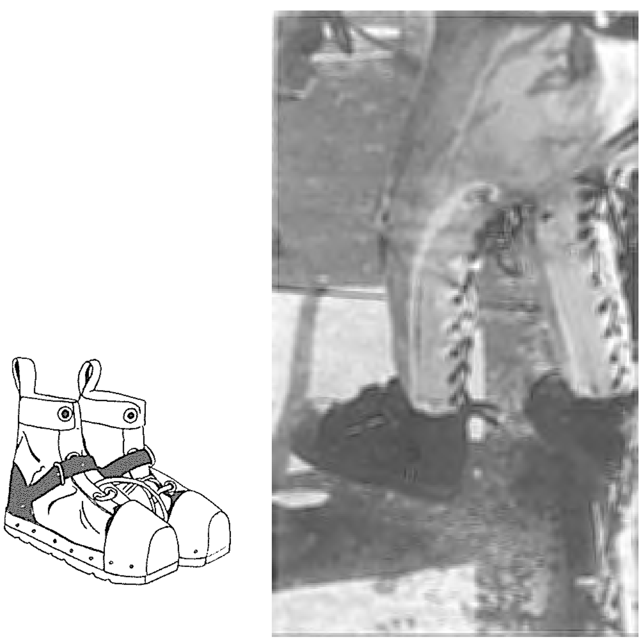


Figure 6-12 Deep-Sea Diving Shoes

THE HOSE GROUP 6.1.1.3 A diver's support from the surface, including the air he breathes, his means of communication and the method whereby he is normally brought up from the bottom, is provided through the hose group. This consists of his air hose and fittings (including the main air control valve), the lifeline/amplifier cable, and the pneumofathometer. These three surface-connected lines are married together into one basic umbilical (tied at three foot intervals) so that they can be handled as one line. To reduce the possibility of fouling, the last 50 feet of the umbilical closest to the helmet is wrapped with canvas.

The air hose is negatively buoyant and is constructed and tested in accordance with MIL-H-2815D to supply air at a maximum working pressure of 600 psig. The hose is furnished in lengths of 200 feet with a male coupling on one end and a female coupling on the other and in 3-foot lengths of "leader hose" with a female coupling on both ends.

Figure 6-13 Air hose, communications cable and fittings shown properly secured to diver.

The 200 foot lengths are used in making up the hose to supply air from the surface to the diver's air control valve. The 3 foot leader hose connects the air control valve with the safety air non-return valve mounted on the air inlet gooseneck. Each length of hose is marked with the month and year of manufacture, the name and trademark of the manufacturer and the words "Divers H.P."

The air control valve is manually operated by the diver to control the flow of air entering the helmet. The body of the valve is a heavy brass casting with threaded male fittings at both openings. Details of the valve design and construction are shown in Figure 6-14.

Figure 6-14 Diver's Air Control Valve

The couplings on air hoses are force-fit, glued and clamped in place for maximum security and strength. The ends of the hose at the fittings, are treated with a rubber compound to keep water from seeping into the braid and causing deterioration of the fabric. For this reason, standard lengths of hose should never be cut back without proper retreatment. The couplings on the hose and valves have a standardized diver's air hose, or submarine, thread (1 1/16 inch x 17 threads per inch).

Adapters are available for making connections with other standard threads which may prove necessary in coupling with the air supply system. The S-reducer connects with a 3/4 inch pipe thread, and the T-reducer connects with the thread on a torpedo air flask (1 1/8" -14 thread per inch). Also, double male and double female couplings are available for matching up the air hose with connections in the air supply system. These adapters are for use on the surface only, and not for underwater connections.

The life-line/amplifier cable has a rubber-coated steel cable core which provides a tensile strength of 2500 pounds. Four insulated conductors (white, green, black and red) are wound around the core and sealed in by a rubber coating which in turn is covered by an oil-resistant neoprene jacket. The finished cable is 5/8" in diameter and weighs about 0.35 pounds per foot dry and is negatively buoyant in the water.

The life-line/amplifier cable is usually made up in lengths of 200 and 600 feet, and each length is furnished with a coupling kit containing necessary plugs, adapters and wrenches. If two units of cable must be connected, the overall strength is reduced to a static load of 1000 pounds which is the breaking point of the plugs.

In use, the diver's end of the cable is connected to the left helmet gooseneck, passed under the right arm (from back to front) and lashed to the right breastplate padeye before it joins the umbilical. At the surface, the cable is plugged into the diver amplifier unit on the support ship.

The final component of the hose group is the pneumofathometer. This is a simple, but accurate, depth-

Figure 6-15 Lifeline, air hose and pneumofathometer (behind right hand) in use for lightweight diving.

measuring device (described on page 4-7) which, when used as a part of a diving outfit, provides surface support personnel with a method of constantly monitoring the diver's depth. One end of a 5/16" diameter oxygen hose is connected at the surface to an air supply and pressure gage calibrated to read in feet of seawater. The other end, which is open to the water, is fastened to the diver's breastplate padeye such that it terminates at the diver's chest level. The depth is determined by the air pressure required to blow and to keep water out of the hose. If the diver is standing, five feet must be added to the gage reading to determine the actual bottom depth.

Lightweight Diving Outfits 6.1.2 The lightweight diving outfit is surface-supplied with air for breathing, but unlike the deep-sea outfit, it does not admit air into the diving dress for buoyancy control. Diving using lightweight equipment is limited in depth depending upon the equipment being used. The U. S. Navy will not permit diving below 90 feet (27.4 meters) using the standard (Jack Browne) mask.

If the Diver's Mask USN MK 1 is used, depths are limited to 130 feet (39.6 meters) without the support of an open bell and 190 feet (57.9 meters) with a bell. The open bell is discussed in Chapter Eleven, Volume Two of this manual. The advantages and disadvantages of lightweight diving equipment are discussed in Chapter Four of this volume.

The basic components of a lightweight outfit are—

The mask group which includes all valving. There are two different models of lightweight masks—the standard or "Jack Browne" rig, and the Diver's Mask USN MK 1.

The diving dress group, which includes the diving dress (with two styles, wet or dry, available), and gloves, shoes, chaffing pants, weighted belt, and knife.

The hose group, which includes the air hose and fittings, life-line, communications cable (if applicable) and the pneumofathometer.

THE MASK GROUP 6.1.2.1 The standard lightweight mask is built around a copper frame with a molded rubber seal and has a large triangular faceplate which gives a wide field of vision. The rubber

Figure 6-16 Lightweight Diving Outfit

seal is designed to match with a corresponding rubber seal around the face-opening of the dress, and the mask is held in place by a head harness. One style of the standard lightweight mask has an inhalation valve on the right side and the exhaust valve on the left. A later style has only the exhaust valve mounted on the left side with an elbow on the right side for attaching the air control valve. The inhalation valve has a two-position handle and was originally designed to permit the addition of a breathing bag to the outfit. Such bags are not used and the valve handle should only be placed in the rear position where it admits air directly from the air hose to the mask. The fitting on the valve for the breathing bag should be capped, and the handle should be safety wired or taped so that it is never placed in the forward position.

The exhaust valve contains a rubber disk which is held closed by water pressure except when the diver

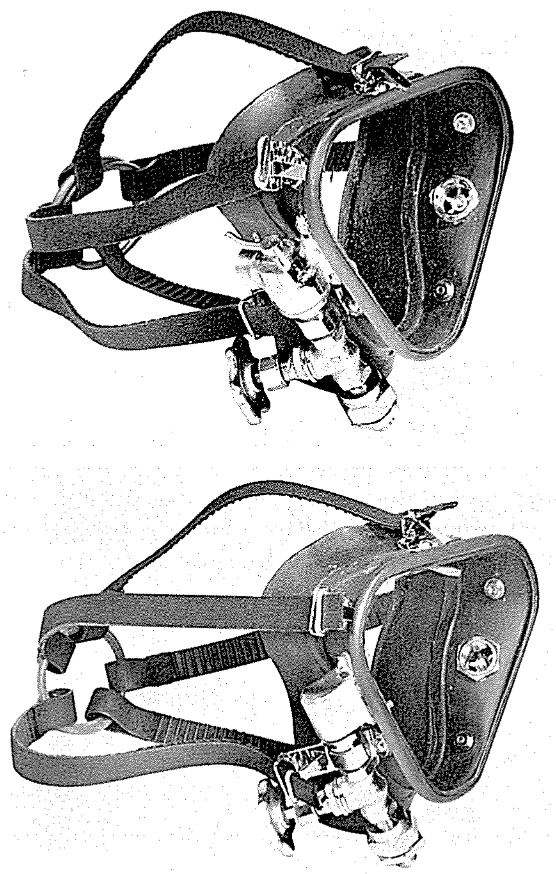


Figure 6-17 Standard Lightweight Mask "Jack Browne"

is exhaling and the additional pressure inside the mask forces the valve open. The exhaust valve can be adjusted, by means of an attached stem, for smooth operation.

Two other valves complete the mask group. These are the **air control** valve and the **non-return valve.** The air control valve screws directly into the inhalation valve (or elbow) on the mask and is used to manually throttle the flow of air entering the mask. The non-return valve performs the same vital function in the lightweight outfit as it does in the deep-sea outfit: to prevent air from escaping back up the air hose and collapsing the lungs in the event of a hose rupture or drop in air pressure. The non-return valve is installed at the inlet of the air control valve, where the match of female-male threads prevent it from being reversed. As an additional safety factor, the body of the valve is stamped with an arrow to indicate the direction of air flow (toward the diver).

The **Diver's Mask USN MK 1** is an improved version of the standard lightweight mask. It permits two-way voice communications between the diver and the surface, and it has features which minimize the dangers of flooding, face squeeze and CO_2 buildup. The diver has the option to breathe in either a demand or free-flow mode or a combination of each. For added safety, this mask may be connected with a self-contained back-up air supply normally carried in a small cylinder on the diver's back or side.

The MK 1 mask is built around a molded fiberglass frame upon which are mounted a rubber face seal, a head harness, a faceplate made of ¼″ acrylic plastic, and a moveable nose pad which can be used by the diver as an aid in equalizing pressure in his ears and sinuses. Other components of the MK 1 mask group installed on the mask are—

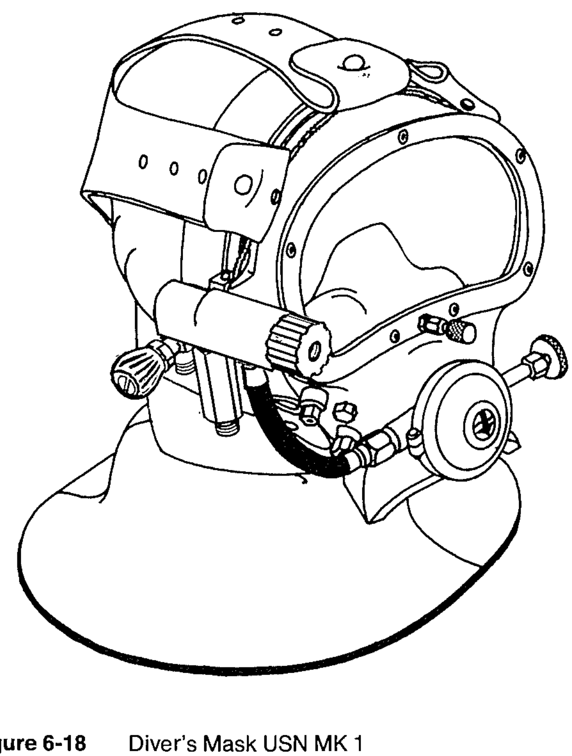


Figure 6-18 Diver's Mask USN MK 1

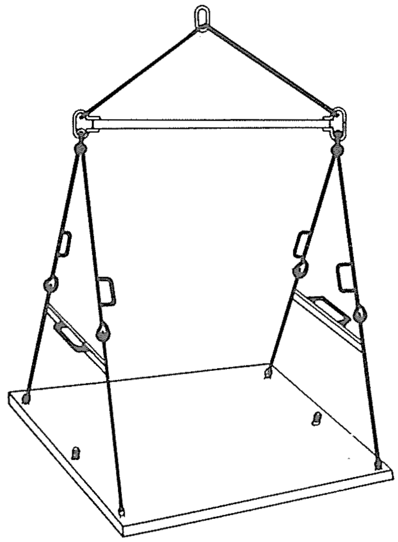


Figure 6-21 Two-Man Decompression Stage

—diving ladder used when entering the water from the side of a small boat. The ladder is made of galvanized steel, and when in use it is held at the correct angle by a pair of struts which hold the ladder out from the side of the boat. These struts may be folded for storage.

—cast iron weights are provided in two sizes: 50 pounds and 100 pounds. Both sizes are used as descending line weights.

—canvas toolbag for carrying tools. The bag may be looped over the diver's arm, or it may be sent down the descending line.

—underwater lights, if conditions permit, may improve the diver's range of vision. A variety of lights are available. One, a medium pressure light satisfactory to a depth of 150 feet, uses a normal 100-watt photoflood bulb or any other bulb with a medium base. A second light, adequate to 500 feet, employs a special 1000-watt lamp in a brass lampholder with a chromium plated reflector and wire grill protector. Another model is also available which has a depth limit of 11,000 feet. Its 1000-watt bulb and reflector are enclosed in a pressure tight cast aluminum housing. All underwater lights must be submerged before they are turned on and be turned off before being taken out of the water to prevent breakage due to thermal shock.

Figure 6-22 Diving Ladder

—a stopwatch for timing the total dive time, decompression stop time, travel time, etc.

—a welding faceplate, used with deep-sea gear, fits over the regular faceplate and reduces the excessive glare produced by welding apparatus. The faceplate has a metal frame with interchangeable lenses and a spring clip for holding the lens in an "open" or "closed" position. The lenses are supplied in three degrees of increasing density designated as #4, #6 or #8. The selection of lens is determined primarily by the degree of turbidity of the water. Relatively clear water will require the use of darker lens than will muddy water.

Accessory storage boxes, tools, and maintenance and repair kits will be described in a later section.

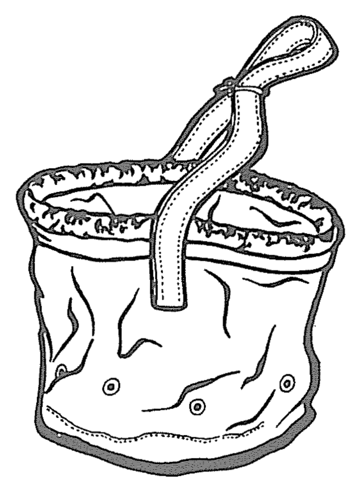


Figure 6-23 Canvas Tool Bag

SURFACE AIR SUPPLY SYSTEMS 6.2

Requirements for Air Supply 6.2.1 The diver's air supply may originate from either an air compressor, bank of high pressure air cylinders or a combination of both. Regardless of the source, the air must meet certain established standards of **purity**, must be supplied in an adequate **volume** for breathing and at a **rate of flow** which will properly **ventilate** the helmet or mask. In the case of the Diver's Mask USN MK 1, if the air supply must support a demand breathing system, it must be capable of providing the maximum instantaneous demand flows of the equipment.

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 dress being used. The Diving Supervisor is directly responsible for determining if the air supply to be used is adequate for each dive and for ensuring proper and continuing availability of the supply.

AIR PURITY STANDARDS 6.2.1.1 Air, if taken directly from the atmosphere and pumped to the diver, may not meet purity standards established by the Bureau of Medicine and Surgery. The air itself may be contaminated by engine exhaust or chemical smog, or even initially pure air may become contaminated while passing through the compressor system.

The quality of the air, as measured at the final outlet valve of any supply system, **must conform** to the following standards—

Oxygen	20% to 22% by volume
Carbon Dioxide	300 to 500 parts per million; 0.03% to 0.05% by volume
Carbon Monoxide	20 parts per million maximum; 0.002% by volume.
Oil, Mist and vapor	5 milligrams per cubic millimeter maximum.
Solid and Liquid Particles	Not detectable except as noted above under oil, mist and vapor
Odor	Not objectionable

To meet these standards, specially-designed non-lubricated compressors must be used, or the air supplied by a standard compressor must be passed through a highly efficient filtration system. The compressed air found in a shipboard service system will usually contain excessive amounts of oil and is not suitable for diving without being 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.

AIR SUPPLY FLOW REQUIREMENTS 6.2.1.2 The required flow from an air supply system depends upon the type of diving apparatus being used. If the air supply system is to be used in conjunction with open-circuit, free-flow apparatus, such as a helmet, flow must be adequate to meet the requirements of ventilation (See Section 3.4.5, Chapter Three). If demand breathing equipment is used, such as the Diver's mask USN Mk I, the supply system must meet the diver's instantaneous peak flow requirements.

Open-Circuit Systems' Requirements—the primary requirement of an air supply system which is to be used with open-circuit equipment is that it must provide a sufficient flow of air to adequately ventilate the equipment. The principle of ventilation is to flush the diving apparatus, whether it's a helmet, mask or recompression chamber, sufficiently to maintain a non-toxic partial pressure of carbon dioxide in the atmosphere which the diver breathes. Ventilation requirements for recompression chambers are discussed in Section 8.4. of Chapter Eight in this manual.

The maximum partial pressures of carbon dioxide which can be tolerated in normal breathing is related to the time of exposure, as shown in Figure 6-24. The recommended nontoxic limit is 0.02 atmospheres (2% surface equivalent). The **exact volume** of air required for adequate ventilation will depend upon two factors: the **amount of carbon dioxide** the diver is producing and the **Mixing Effectiveness Factor** associated with his apparatus.

Carbon dioxide is a by-product of the diver's metabolism, and the quantity produced is proportional to the

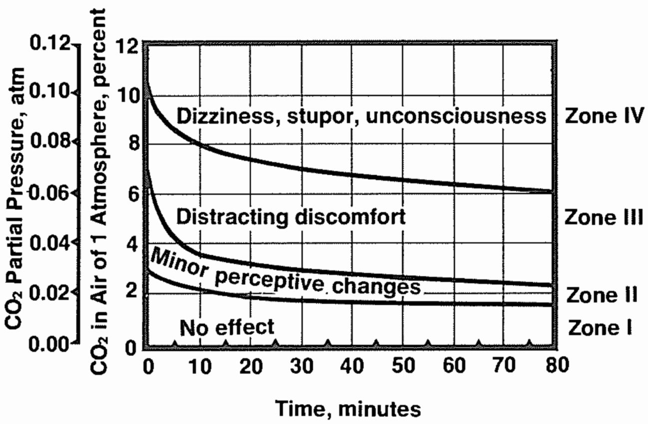


Figure 6-24 Relation of physiological effects to carbon dioxide concentration and exposure period.

amount of oxygen which the diver consumes. Oxygen consumption, in turn, varies according to the amount of energy exerted by the diver as shown in Figure 5-28 of Chapter Five. The ratio of carbon dioxide produced to the oxygen consumed is called the respiratory quotient and normally is between 0.85 and 1.0.

The Mixing Effectiveness Factor is the ratio of the percentage of carbon dioxide in the inhaled air to the percentage of carbon dioxide in the exhausted air. It is dependent upon the design of the apparatus and may also vary with depth and the position of the head.

Figure 6-25, taken from the U. S. Navy Diving Gas Manual (NAVSHIPS 0994-003-7010), shows the relationship of the Mixing Effectiveness Factor to depth for the U. S. Navy Mark V helmet. Similar values for the standard lightweight mask and the Diver's Mask USN Mk I (when used as an open-circuit system) have not been determined; a value of 1.0 (or 100% effectiveness) should be used.

The equation for determining the flow of air required to properly ventilate each helmet or mask is shown below—

$$Q = \frac{Patm \times Oslm \times R \times F}{26.3\ (C_2 - C_1 \times Patm)} \qquad \text{(equation 6-1)}$$

Where—

Q=required flow of air in standard cubic feet per minute

Patm=Pressure at depth (D), in atmospheres= $\frac{D+33}{33}$

Oslm=Oxygen requirement, in surface liters per minute

R=Respiratory quotient= $\frac{\text{Vol of } CO_2 \text{ produced}}{\text{Vol of } O_2 \text{ consumed}}$

F=Mixing Effectiveness Factor

C_2=Desired partial pressure of CO_2, in atmospheres

C_1=Partial pressure of CO_2 in the air supply, in atmospheres

This calculation can be simplified by giving three of the variables fixed values which are selected to ensure a maximum safety factor—

Oslm=2.6 surface liters per minute (value representing heavy to severe exertion)

R=0.9 (the highest value likely to occur)

C_2=0.02 atmospheres (the desired CO_2 level)

Substituting these values gives the equation—

$$Q = \frac{0.0893\ Patm \times F}{0.02 - C_1 \times Patm} \qquad \text{(equation 6-2)}$$

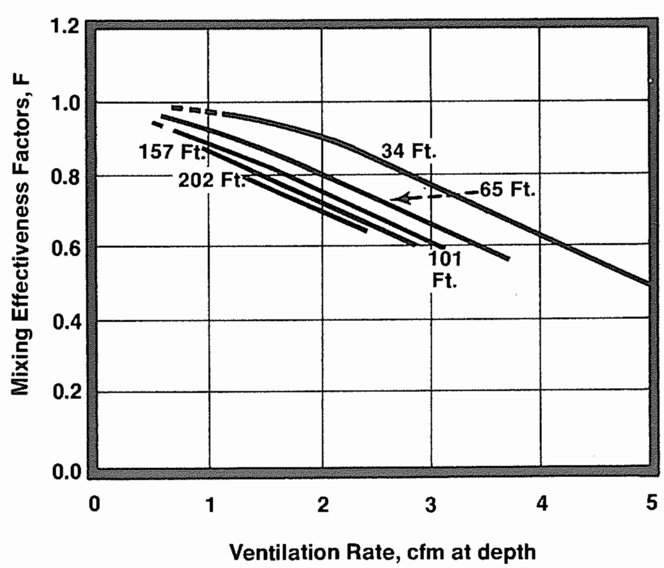


Figure 6-25 Variations of Mixing Factor with Depth and Ventilation Rate for Mark V Diving Helmet.

Demand Systems' Requirements—The required flow of air supplied to a demand breathing apparatus, such as the Diver's Mask USN MK 1, is based upon the diver's maximum instantaneous flow requirements. A recent study on demand breathing requirements (TECHNOTE 2-72, NAVSHIPS OOC S-03, 22 May 1972) determined that, during the initial period of heavy breathing, an instantaneous flow of approximately 365 standard liters per minute (13.9 standard cubic feet per minute) is approached.*

In order to meet this requirement, the flow capacity of the air supply system must be at least equivalent to those specified in Figure 6-26.

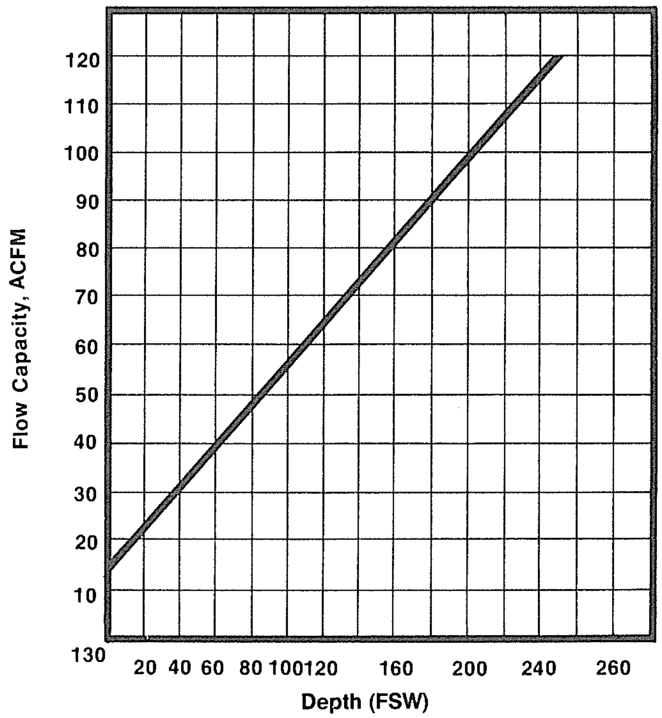


Figure 6-26 Air supply system capacity requirements for demand breathing, surface-supplied apparatus.

SUPPLY PRESSURE REQUIREMENTS 6.2.1.3 In order to supply the diver with an adequate flow of air, the air source must deliver air at sufficient pressure to overcome the bottom seawater pressure and the pressure drop which will be introduced as the air flows through the hoses and valves of the system. Additionally, as a safety factor, the air reaching the diver must have an overbottom pressure—that is, a pressure which is higher than the pressure at operating depth. This will help guard against injury from squeeze if the diver should suddenly fall and require additional pressure.

The minimum overbottom pressure must be 50 psi for dives of less than 120 feet, and 100 psi for dives greater than 120 feet. The minimum supply pressure is calculated by the following formulae—

$P_s = P_d + P_l + 50$ (less than 120 feet)

$P_s = P_d + P_l + 100$ (greater than 120 feet)

(equation 6-3)

Where

P_s=Pressure of the air supply at the source, psig

P_d=Pressure at depth, psig

P_l=Pressure losses in the hose, valves and regulators, psig

*The standard liter is defined at 0°C (32°F) and the standard cubic foot is defined at 15.5°C (60°F). Although 1 ft^3 = 28.3 liters, 1 standard ft^3 = 26.3 standard liters.

The U. S. Navy Diving-Gas Manual (NAVSHIPS 0994-003-7010) provides a nomograph to calculate the pressure losses through ½ inch I.D. diving hose for various flows. It also includes data for determining the losses through the diver's control valve, 3 ft. hose and non-return valve of the deep-sea Mark V helmet. Comparable data for the lightweight diving masks has not been determined; consequently, a loss of 10 psig through the valves (P) should be used.

OTHER AIR SUPPLY CONSIDERATIONS 6.2.1.4 As previously stated, the air reaching the diver must meet certain standards of purity and must be delivered in adequate volume and at the proper pressure. Several other factors must be considered, however, when preparing the air supply.

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 in the supplied air is normally accomplished by one or both of the following methods—

A. 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 (Figure 2-19, Chapter Two). Therefore, the relative humidity of the air is reduced.

B. Cooling—Cooling the air prior to expanding it raises its relative humidity, permitting some of the water vapor to condense. The condensed liquid may then be drained from the system.

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 stand-by diver should he be needed. Finally, but of prime importance, a back-up system of sufficient capacity to support all divers must be immediately available in the event of a failure in the primary system.

The characteristics of the various systems of air supply, and the factors to be applied in determining the adequacy of each for any given dive, are presented in the following sections.

Air Supply Systems 6.2.2 There are three basic types of air supply systems which can deliver air meeting the basic standards and requirements outlined above. These are—

—engine-driven air compressors

—high pressure air cylinder banks

—steam or electrically-driven shipboard air systems.

Whichever system is to be used, it must be in good repair, properly serviced and manned by trained personnel. The supply system must be provided with appropriate pressure gages, flow meters, coolers, separators, filters, manifolds and connectors, all as indicated by the needs of the operation and the type of supply.

In working with all air supplies, compliance with two rules is mandatory—

A. All valves and switches which directly influence the air supply must be tagged with the warning—

DIVER'S AIR SUPPLY—DO NOT TOUCH

All personnel, both diving and non-diving, who may be in the vicinity of such valves or controls during an operation must be informed not to touch any valve so marked.

B. A volume tank or accumulator must be part of the air supply system and be located between the supply source and the diver's hose connection. This tank serves to maintain an immediate, available reserve air supply should the primary supply source fail.

AIR COMPRESSORS 6.2.2.1 Most air supply systems used in Navy diving operations include at least one air compressor as a primary source of air. To properly select such a compressor, it is essential that the diver has a basic understanding of the principles of gas compression. Generally, two types of air compressors are available, the dynamic type (centrifugal) and the positive displacement type.

The centrifugal compressor has, to date, been limited to use on some aircraft carriers where high capacities of air are required to support aircraft starting and maintenance. Its compact design combined with its high rpm suggest that any significant field repairs of this type of compressor would be difficult.

Positive displacement compressors may be further categorized as rotary and reciprocating compressors. Rotary compressors usually have only one stage in which air is compressed by the action of a rotor in an eccentric stator. The air is normally contained by sliding vanes (Figure 6-27a), but in the case of the liquid ring rotary compressor (Figure 6-27b) water forms the containing seal. Rotary compressors are normally limited to pressures less than 100 psi and, therefore, are only adaptable to very shallow diving operations.

Reciprocating compressors are the most common compressors found in air diving operations. They are capable of providing capacities sufficient to support almost any surface-supplied air diving operation and recompression chamber. This type of compressor is also capable of attaining pressures high enough to charge SCUBA cylinders and high pressure cylinder banks, although at these pressures the capacity is normally low.

The techniques for determining the flow and pressure requirements of an air supply system to support

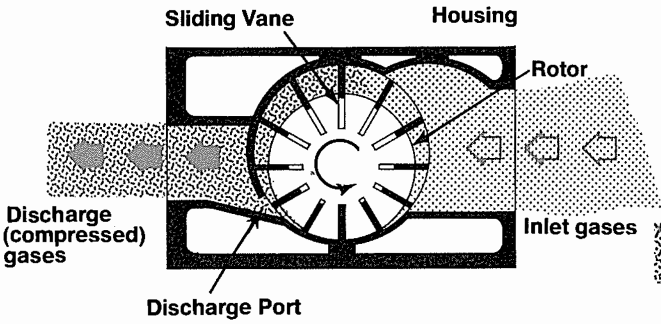


Figure 6-27a The Sliding Vane Rotary Compressor is a positive displacement, constant-volume unit with variable discharge pressure.

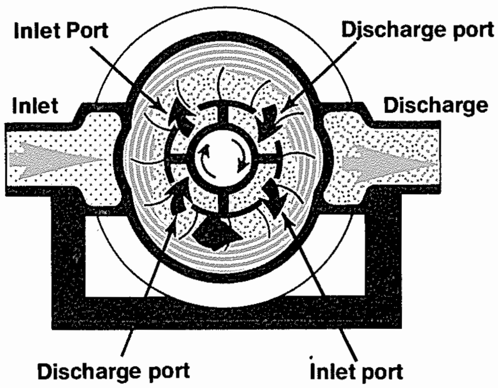


Figure 6-27b A Liquid Piston Rotary Compressor.

various types of diving apparatus are the subjects of sections 6.2.1.2 and 6.2.1.3 of this chapter. An air compressor must now be selected which will perform to these requirements. Normally, reciprocating compressors have their rating (capacity in scfm and delivery pressure in psig) stamped on the manufacturer's identification plate. This rating is based on inlet conditions of 70°F (21.1°C), 14.7 psia barometric pressure, 36% relative humidity and an air density of 0.075 lbs/ft^3. If inlet conditions vary from these, the actual capacity will either increase or decrease from its rated values (Figure 6-29).

Sometimes the compressor rating is not provided directly and the capacity must be calculated based on the compressor displacement. All industrial compres-

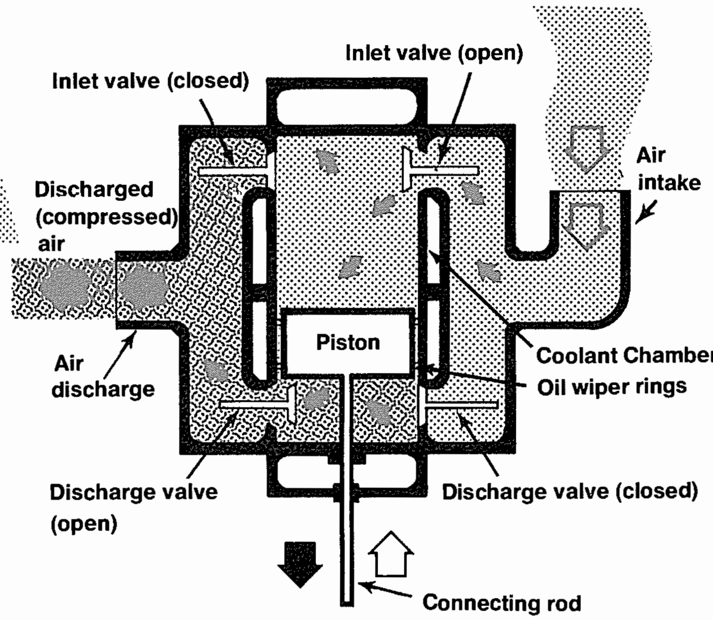


Figure 6-28 Sectional view of a typical double acting piston compressor.

sors are stamped with a code consisting of at least two, but usually four or five numbers, as follows—

6 x	6 x	4 x	2 -	4
1st stage 1st piston 6″ diameter	1st stage 2nd piston 6″ diameter	2nd stage 4″ diameter	3rd stage 2″ diameter	4″ stroke

Using this code, the ideal displacement per revolution of the compressor is equal to the volume of the first stage cylinder(s).

First Stage Volume

$$= \frac{3.14 \times (\text{diameter})^2}{4} \times \text{stroke} \times \text{no. of cylinders} \qquad \text{(equation 6-4)}$$

$$= \frac{3.14 \times 6^2 \text{ in.}}{4} \times 4 \text{ in.} \times 2 \text{ cylinders}$$

$$= 226 \text{ cubic inches per revolution}$$

If the compressor operates at 440 rpm, then the displacement capacity is—

$$V_{ideal} = 226 \text{ in}^3/\text{rev.} \times 440 \text{ rev/min}$$
$$= 99{,}440 \text{ in}^3/\text{min}$$
$$= 57.6 \text{ scfm}$$

The actual capacity of the compressor will always be less than the ideal capacity 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 4 inches or larger will normally have an actual capacity of about 90% of their ideal capacity. The smaller the first stage piston the lower the efficiency will be (because the clearance volume represents a greater percentage of the cylinder volume).

Other features of reciprocating compressors which should be understood by those who operate and use them include lubrication, intercooling, condensate collection and filtration.

All reciprocating piston compressors must be lubricated. The lubricant serves four functions—

- to prevent wear between rubbing surfaces
- to seal close clearances
- to protect against corrosion
- to transfer heat and minute particles produced from wear away from points of contact

Unfortunately, this lubricant will vaporize into the air supply and, if not condensed or filtered out, will

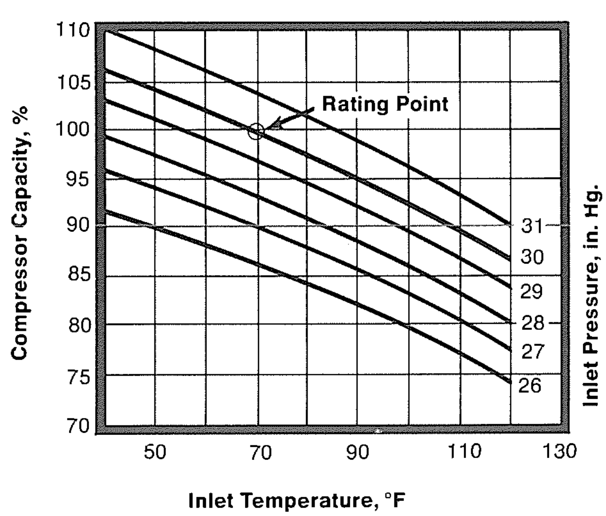


Figure 6-29 Relation of Compression Capacity to Inlet Temperature and Barometric Pressure.

reach the diver's lungs. Although every attempt should be made to limit the amount of lubricant in the air provided to the diver, the only assured prevention against harming the diver is to use non-toxic lubricants. Any lubricant used in diving air compressors must conform to military specification L-17672, two of which are 2110 T-H and 2135 T-H (both having a basestock of naphthenic mineral oil).

It should also be noted that the air in the higher stages of a compressor has a greater amount of lubricant injected into it than in the lower stages. Therefore, it is recommended that the compressor selected for a diving operation provide as close to the required pressure for that operation as possible. Excess pressure means unnecessary staging which results in a buildup of lubricant in the supply.

Intercoolers are heat exchangers which are placed between the stages of a compressor to control the air temperature. Water, flowing through the heat exchanger counter to the air flow, serves both to remove heat from the air and to cool the cylinder walls. During the cooling process, water vapor is condensed out of the air and collected in condensate drains. This water must be periodically discharged throughout the operation of the compressor.

Finally, as the air is discharged from the compressor, it must pass through an oil separator and a filter to remove lubricant, aerosols and particulate before it enters the accumulator.

Proper design of the air supply system leading into and out of the compressor is essential if the compressor is to perform according to its rating. Unfortunately, these areas are often overlooked.

A pressure regulator should be installed between the compressor outlet and the accumulator so that the compressor is always working against a back pressure. A compressor will only compress air to meet the supply pressure demand. If no demand exists, air will simply be pumped through the compressor at essentially 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 design efficiency of the unit and the capacity is reduced. Additionally, compres-

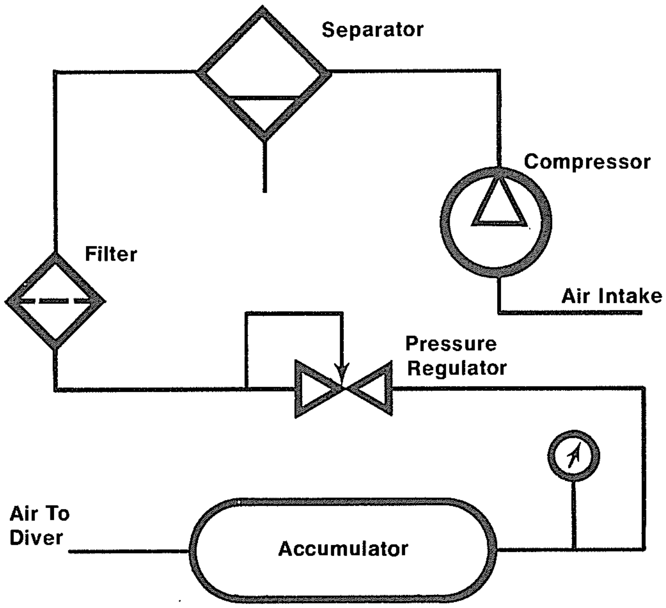


Figure 6-30 Schematic of major components of a compressor-equipped air supply system.

sion eliminates water vapor (absolute humidity) from the air. Reducing the amount of compression increases the amount of water vapor in the air going to the diver.

The air supplied from the compressor will expand across the pressure regulator and enter an accumulator. As the pressure builds up in the accumulator, it will eventually reach the relief pressure of the compressor at which time the excess air will simply be discharged to the atmosphere. Some electrically-driven compressors are controlled by pressure switches installed in the accumulator. When the accumulator pressure reaches the upper limit, the electric motor is shut off. When sufficient air has been drawn from the accumulator to lower its pressure to some lower limit, the electric motor is restarted. Electrically-driven compressors which are equipped with this type of control system must never be used to support diving operations which require air pressures above the lower limit pressure setting.

All piping in the system must be designed and installed to minimize pressure drops. Intake ducting, especially, must be of sufficent diameter that the rated capacity of the compressor will not be limited. All joints and fittings must be checked for leaks using soapy water; 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 lashed in place. Most portable compressors are provided with lashing rings for this purpose; however, it is recommended that these rings not be depended upon to secure the unit at greater than a 15 degree deck inclination.

Figure 6-31 provides a convenient graph for determining the capability of an air compressor to support surface-supplied diving using the Mark V helmet based on the procedures outlined in Section 6.2.1.2. To use this graph, locate the number of divers on the baseline which most accurately represents the level of work to be done (heavy or light). Move upward to the depth corresponding to the depth of the dive and read the compressor output capacity based on standard inlet conditions. Adjust the capacity for variations in inlet conditions according to Figure 6-29, and find the compressor manifold pressure on Figure 6-31 required to provide this capacity.

Example—

Problem—Two divers using deep-sea gear are to perform a repair operation at 210 feet. The hose length to each diver is 500 feet. Atmospheric conditions are 80°F and 30 in. Hg. What are the capacity and pressure requirements of the compressors needed to support this dive?

Solution—The total number of divers to be supported is 3, the two working divers plus one standby diver.

1—Find the compressor output capacity from figure 6-31 for divers doing heavy work at 210 feet.

Capacity (at standard conditions)
= 112 scfm

2—Find the compressor capacity from Figure 6-29 for 80°F and 30 in. Hg.
Rating = 97.5%

3—Compute the required compressor capacity.

$$\text{Required Capacity} = \frac{\text{Standard Capacity}}{\text{Rating/100}}$$

$$= \frac{112}{.975}$$

$$= 115 \text{ scfm}$$

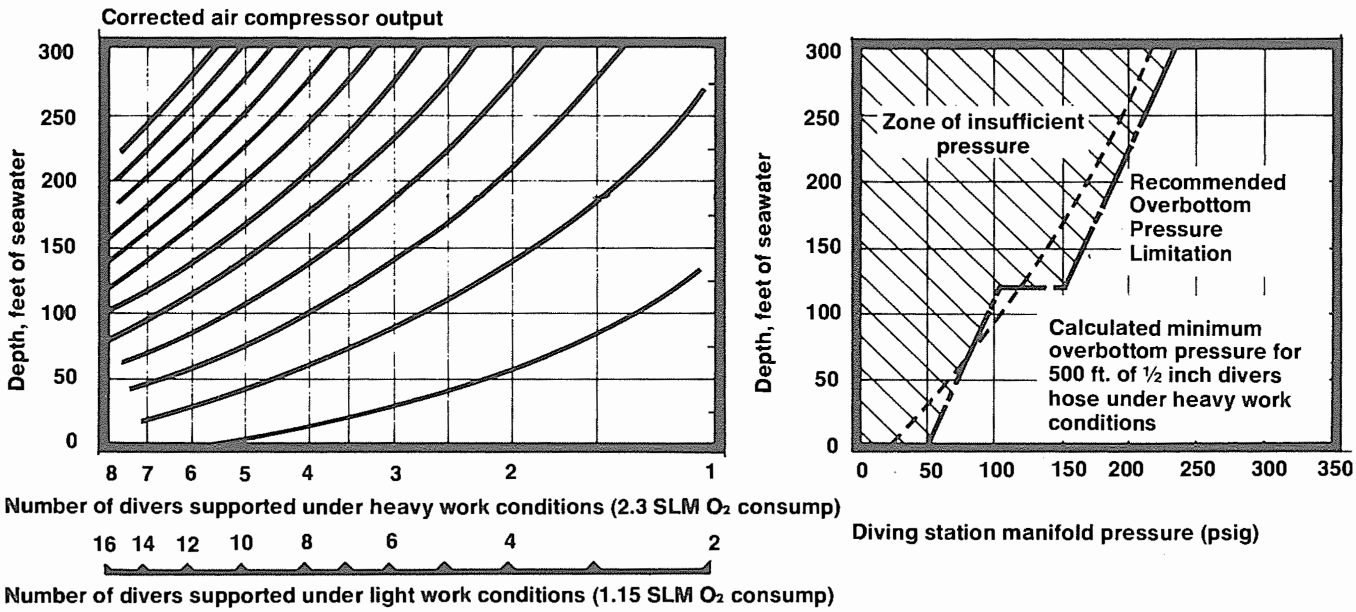


Figure 6-31 Compressor Requirements—Mk V

4—Find the compressor manifold pressure from Figure 6-31.

Manifold Pressure=175 psig (min.)
=195 psig (Navy recommended)

To support the above operation, two diving air compressors capable of 115 scfm at a minimum of 195 psig will be required. The second compressor should be started and left running as an emergency backup.

HIGH PRESSURE AIR CYLINDERS 6.2.2.2 A submarine high-pressure air cylinder (flask) is an 8-cubic foot tank designed to hold air at a rated pressure of 3,000 psi. A convenient and satisfactory diving air supply system can be achieved with the use of four or more of these flasks. A suitable system can also be set up using other cylinders which are suited to diving applications. Any cylinder to be used as a diving air supply unit must bear appropriate DOT or Navy symbols certifying that the cylinders meet high-pressure requirements (See Chapter Five).

The complete air supply system includes the necessary piping and manifolds, a high-pressure strainer, a pressure reducing valve, and at least a 1 cubic foot volume tank. A high-pressure gage must be located ahead of the reducing valve, and a low-pressure gage must be connected to the volume tank. (A detailed plan and bill of materials for such a system is contained in BUSHIPS Plan 19738-S4904-298223 Alt 1.)

In using this system, one tank must be kept in reserve, and no more than two divers may be supplied at one time. 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 will be limited to the length of time the cylinders will provide air before being depleted to a level that is 220 psi above the divers' working pressure. As this level is approached, the divers must be brought up from the bottom. The reserve tank may be put on the line once the divers are on their way to the surface and must be of sufficient capacity, determined in advance, to support their decompression requirements.

If cylinder banks are used to back-up a compressor supply, the bank must be manifolded with the primary source so that an immediate switch from primary to secondary air is possible.

As with SCUBA operations, the quantity of air which can be supplied by a system using cylinders is determined by the initial capacity of the cylinders and the depth of the dive. The duration of the air supply must be calculated in advance, and must include any provisions for decompression stops.

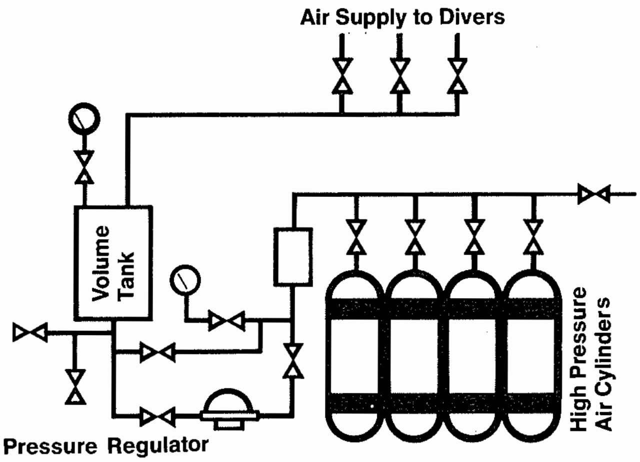


Figure 6-32 Typical High Pressure Cylinder Bank Air-Supply System Schematic

In calculating the capacity of air available from a bank of high pressure cylinders, provisions must be made for the 220 psig minimum bank pressure requirement and for the one atmosphere of air which will be needed to fill the piping, hose and diving apparatus. The equation for calculating this capacity is—

$$Va = \frac{Nc \times Vr \times (Pc - Pd - 234.7) \times F_T}{Pr}$$ (equation 6-5)

Where,

V_a=Capacity available, scf

N_c=Number of cylinders available

V_r=Rated capacity of cylinder, scf

P_c=Measured cylinder pressure, psig

P_d=Pressure at depth, psig

F_T=Temperature correction factor (page 5-17)

P_r=Rated pressure of cylinders, psig

The 234.7 in this equation represents the minimum overbottom pressure (220 psig) plus one atmosphere for filling the system (14.7 psig). The rated capacity and pressure for a variety of commonly used cylinders is given in Table 6-2.

To determine the duration of this air supply, the ventilation flow rate (Q) of the divers must be calculated using equation 6-1 or 6-2. These equations consider only one diver, so the flow rate must be multiplied by the number of divers (N_d) that may be using the air supply at the same time (including a standby diver). The equation for the duration is then—

$$\text{Duration} = \frac{V_a}{N_d Q}$$ (equation 6-6)

TABLE 6-2
COMPRESSED GAS CYLINDER DATA

Gas	Working Pressure psig	Rated Capacity-ft³	Color Markings Band/Body
Air	1800	200	None
Air	2265	250	Green/Black
Helium	2265	217	Buff/Gray
Hydrogen	1800	176	Black/Yellow
Nitrogen	1800	184	Black/Gray
Oxygen	1800	200	Green

Example—

Problem—One diver is to make a dive to 210 f.s.w. using a deep-sea diving outfit. A bank of ten 200 cubic foot cylinders are to be used as the air supply. The diver is expected to work hard. The Mixing Effectiveness Factor of his helmet is 0.95, and the partial pressure of CO_2 in the air supply is 0.001 atmosphere. The cylinder bank pressure is 1700 psig at a temperature of 70°F.

What is the maximum amount of time that the diver may spend on the bottom?

Solution—Calculate the required ventilation flow rate using equation 6-2—

$F = 0.95$

$C_1 = 0.001$ atmospheres

Patm = (210 + 33)/33 = 7.37 ata.

$$Q = \frac{0.0893 \times 7.37 \times 0.95}{0.02 - (0.001 \times 7.37)}$$

$Q = 49.5$ scfm

Calculate the available capacity of the air supply using equation 6-5—

Nc = 10 − 1 reserve = 9

Vr = 200 scf } Table 6-2
Pr = 1800 psig }

Pc = 1700 psig

Pd = 210 x (14.7/33) = 93.5 psig

Ft = 1.00 (page 5-17)

$$Va = \frac{9 \times 200 \times (1700 - 93.5 - 234.7) \times 1.00}{1800}$$

Va = 1372 scf

Calculate the duration using equation 6-6—

$$Nd = 1 + 1 \text{ standby} = 2 \text{ divers}$$

$$\text{Duration} = \frac{1372}{2 \times 49.5}$$

$$\text{Duration} = 13.9 \text{ minutes}$$

For a dive to 210 f.s.w. for 13.9 minutes, decompression is required. The quantity of air needed to support the decompression of the diver must be calculated to determine if the one cylinder held in reserve is sufficient. Based on the 210/15 schedule of the U. S. Navy Standard Air Table (Chapter Seven), and a fixed ventilation flow rate of 4.5 acfm, the quantity of air required for decompression is—

$$\frac{\text{Stop Depth} + 33}{33} \times \text{Ventilation Flow Rate} \times \text{Stop Time} = \text{Quantity of air Needed at Stop}$$

$$\frac{30 \text{ f.s.w.} + 33}{33} \times 4.5 \text{ acfm} \times 1 \text{ min} = 9 \text{ scf @ } 30'$$

$$\frac{20 \text{ f.s.w.} + 33}{33} \times 4.5 \text{ acfm} \times 5 \text{ min} = 36 \text{ scf @ } 20'$$

$$\frac{10 \text{ f.s.w.} + 33}{33} \times 4.5 \text{ acfm} \times 13 \text{ min} = 77 \text{ scf @ } 10'$$

$$\text{Total} = 122 \text{ scf}$$

Since each cylinder has a capacity of 189 scf @ 1700 psig, one cylinder is sufficient as a reserve.

SHIPBOARD AIR SYSTEMS 6.2.2.3 Many Navy ships have permanently-installed shipboard air supply systems which provide either low-pressure, high volume air for operating pneumatic equipment, or high-pressure air for charging air-driven torpedo systems. These systems may be used in support of diving operations provided that they meet the fundamental requirements of purity, capacity and pressure.

In operation, a volume source (such as a steam or electrically-driven rotary compressor) pumps air into an **accumulator**, which is simply a storage tank. For diving air supply, the flow from the accumulator must be passed through appropriate piping, gage, filtration and separation systems. The compressor will automatically keep the accumulator "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 rated capacity of the system. For example:

The capacity of a compressor is 15 cubic feet per hour, or 0.25 acfm, at 2,500 psi. This is equal to 171 atmospheres absolute [(2500/14/7) + 1] and the output of 0.25 acfm would equal 0.25 x 171, or 42.75 scfm at surface pressure. This system could therefore provide the necessary 4.5 acfm to a diver at 9.5 atmospheres absolute, or at a depth of 280 feet. However, this does not provide for any overpressure or reserve capacity, and under no conditions should a diver work at the capacity limit of his air supply.

DIVER COMMUNICATIONS 6.3

The surface-supplied diver has one or two means of communicating with the surface-support team, depending upon the type of equipment he uses. If using either the deep-sea outfit or the lightweight outfit with the Diver's Mask USN MK 1, he has both voice communications and line-pull signals available. With this equipment voice communications are to be the primary means of communication. Line-pull signals serve as a backup. If the diver uses the standard lightweight mask (Jack Browne), his only available means of communication is through line-pull signals.

Direct diver-to-diver conversations are possible with the standard Mark V helmet, since the metal of the helmet serves as a sound conductor. The two divers need only touch helmets to talk with each other. Other diver communications may be the same as used in SCUBA operations: diver-to-diver hand signals, slate boards and signal flares.

Diving Intercommunication Systems 6.3.1

There are three types of diving intercommunication systems presently available for Navy diving operations—

- Model 1 Diver's Intercommunication System (MIL-I-16421B), used with the deep-sea diving outfit.
- Model 2 Diver's Intercommunication System (MIL-I-16421C), used with either the deep-sea diving outfit or the lightweight diving outfit with the Diver's Mask USN MK 1.
- Two-Diver Hardwire Communications System (Mini-communicator), used with the lightweight diving outfit with the Diver's Mask USN MK 1.

Each system provides hardwire communications to at least two divers from a common amplifier on the surface. The major components of each system include the divers' speakers and microphones, combination life-line and amplifier cables for each diver, an amplifier and the tender's speaker and microphone.

MODEL 1 DIVER'S INTERCOMMUNICATION SYSTEM 6.3.1.1 The Model 1 Intercommunication System, shown in Figure 6-33, has provided voice communications to deep-sea divers for over thirty years. This time proven equipment consists of—

- the diving amplifier
- the diver's reproducer
- the combination life-line/amplifier cable

The diving amplifier is the basic power unit and control panel for the intercom system. It includes a combination speaker/microphone, selector switches permitting communications with as many as three divers, and volume and tone controls for each diver. The tone controls are often useful in reducing the interference from background noise. Low-frequency machinery noise can be partially masked out by boosting the treble. Increasing the bass will sometimes minimize the high-frequency hiss of air in the helmet and valves.

The amplifier can be powered by 12 volt DC, 110 volt DC or 110 volt AC, and an individual power jack and power cord is provided for each supply. ONLY ONE POWER SOURCE MAY BE USED AT A TIME; otherwise, the unit will short-circuit. Jack covers should always be placed on the power inputs which are not in use.

The intercom system is operated by a designated tender at the diving station. This tender monitors voice communications and keeps an accurate log of significant messages. All hands on the diving station, however, are usually able to hear the communications from the divers.

In normal operations the messages from all the divers will be continually monitored at the station. To pass a message back to one diver, the operator must depress the appropriate "tender-to-diver" switch. Only that diver will hear the talker. Diver-to-diver communications are controlled by the intercom operator through manipulation of "Diver-to-Diver" switches.

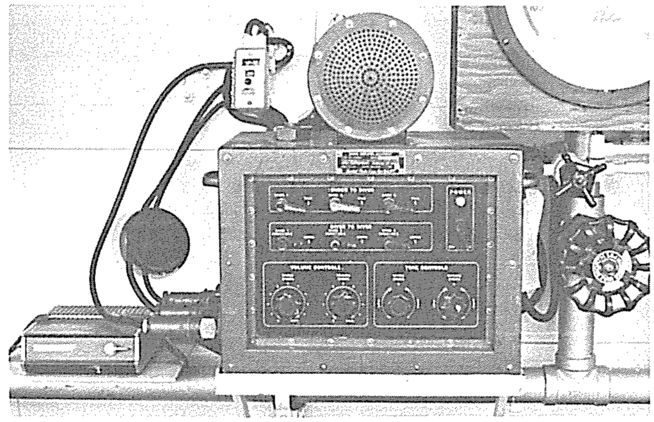


Figure 6-33 Model 1 Diver's Intercommunication System

Figure 6-34 Model 2 Diver's Intercommunication System

Because the diver-to-diver circuit can handle only a one-way communication, talker procedures similar to those used on a voice radio circuit are employed. For example, a conversation between two divers will be handled in this manner:

> One diver initiates the conversation by telling the tender, "Red diver calling green diver". The tender presses the key for "tender to red diver" and says, "go ahead". He immediately releases that key and depresses the appropriate "diver-to-diver" key. Red diver gives his message to green diver, and when finished, will say "Over". The tender must then release the first diver-to-diver key and depress another to permit green diver to talk with red diver. When green diver is finished, he will also say "Over". This switching back and forth will continue until the divers signify "end of call", at which time the tender will return all switches to their normal position.

Other "radio terminology" should be avoided, and conversation kept brief and simple. All persons using the intercom system should lower the pitch of their voices and take care to speak slowly and distinctly.

The amplifier should always be grounded to guard against shock to the tender or to the diver. The ground may be provided by a grounded power source, but since the unit may frequently be used on battery power when operating from a wooden boat or raft, a separate grounding post is provided. This may be connected using #10 gage wire or larger with a metal diving ladder or any other metal which is in contact with the water.

From one to three divers are connected with the amplifier unit by the combination life-line/amplifier cable. The topside end of this cable is plugged into appropriately numbered or color-coded diver's jacks on the right side of the unit. Unused jacks should be kept covered.

The diver's reproducer, mounted in the Mark V helmet between the top and left ports, serves as a dual microphone/speaker.

MODEL 2 DIVER'S INTERCOMMUNICATION SYSTEM 6.3.1.2 The Model 2 Intercommunication System, Figure 6-34, is similar to the Model 1 System except that it is a party-line system. This means that any diver may talk to any other diver and to the tender without switching. The tender may connect himself into the party system or, through appropriate switching, he may interrupt all conversation to speak.

Each diver station is equipped with a microphone, pre-amplifier and a set of ear phones. When used with the MK 1 mask, bone conductor ear phones are installed. If used with the Mk V helmet, the standard reproducer must be taken out of the helmet and replaced with a microphone-pre-amplifier-headset combination which matches the characteristics of the Model 2 System. Also, the amplifier cable must be rewired to match the Model 2 cable configuration.

A 300 foot, 4-conductor, shielded cable (FSS-2) connects each diver with the Model 2 Amplifier. This waterproof amplifier, measuring approximately 16" deep x 16½" wide x 10" high and weighing about 33 pounds, may be powered by an internal 24 volt battery pack, an external 18-28 VDC supply or an external 50-60 Hz 120 VAC (80-130 VAC) supply.

The tender may operate the system using either the built-in loudspeaker and hand-held microphone, or via the headset and boom-mounted microphone. His controls consists of a tone control, which regulates the frequency response to the amplifier, and four volume controls, one for each diver and one for himself.

TWO-DIVER HARDWIRE COMMUNICATION SYSTEM 6.3.1.3 This system, designated the Mini-communicator, is designed to be used with the lightweight outfit with the MK 1 mask in remote areas where sophisticated controls are not available. Its design features ruggedness, simplicity, portability and a self-contained power supply.

The Mini-communicator, shown in Figure 6-35, interfaces with the communication system provided with the Diver's Mask USN MK 1. Special underwater connectors, however, must be installed on the mask in place of the standard terminal posts. Matching connectors are molded to the end of the amplifier cable (a 250', 4-conductor cable).

All controls are on the waterproof tender control box, which is slung over the tender's shoulder. Controls consist of a push-to-talk button and a volume control. The tender listens to both divers simultaneously by means of the speaker mounted on the control box or the headset which plugs into the box. His only means of speaking to the divers is via the boom-mounted microphone on the headset.

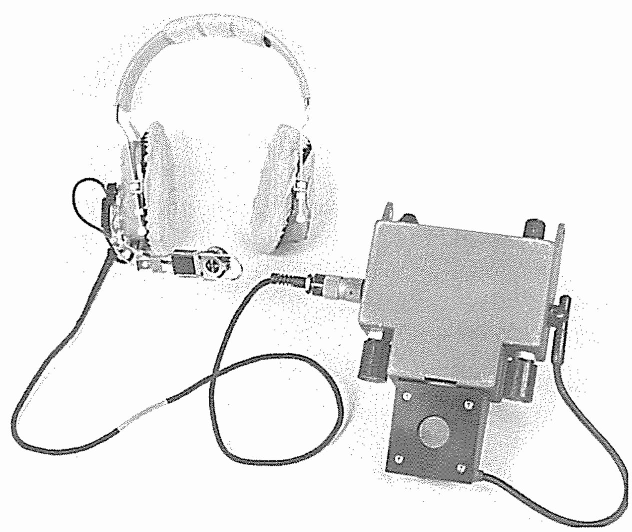


Figure 6-35 Two-Diver Hardwire Communication's System

Line-Pull Signals 6.3.2 A line-pull signal consists of one or a series of sharp, distinct pulls on the line which are strong enough to be felt by the diver but not strong enough to pull him away from his work. For a signal to be felt by the diver, all slack must be taken out of the line before the signal is given.

The line-pull signal code has been established over many years of experience. Standard signals are applicable to all diving operations; special signals may be arranged between the diver and tender to meet particular mission requirements. Most signals must be acknowledged as soon as they have been received. This acknowledgement consists of replying with the same signal. If a signal is not properly returned by the diver, the signal should be re-sent from the surface. A continued absence of confirmation must be assumed to mean one of three things—

—the line has become fouled

—there is too much slack in the line

—the diver is in trouble

If communication is lost, the Diving Supervisor must be immediately notified, and steps taken to identify the problem. The situation should be treated as an emergency (See section 8.5.1.6, Emergency Procedures for Loss of Communications).

There are two line-pull signals which need not be answered immediately. One of these, from diver to tender, is "Haul me up". Sending an acknowledgement will merely waste time, as the diver will quickly know that the action is being taken. The other signal, from tender to diver, is "Come up". This signal must not be acknowledged until the diver is ready to leave the bottom. If for some reason the diver cannot respond to the order, he must communicate the reason via the voice intercom system or through the use of the line–pull signal meaning "I understand you", followed (if necessary) by an appropriate emergency signal.

A special group of "Searching Signals" is used by the tender to direct a diver as he moves 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. This means, "interpret succeeding signals as searching signals". When the tender wants to revert to standard signals, he sends a seven-pull signal which means "searching signals are no longer in use". Only the tender uses search signals; all signals from the diver are standard signals. To be properly oriented for the use of searching signals, the diver must position himself facing the line (either his life-line or a descending line, if a distance line is being employed).

Both the standard and searching line-pull signals are given in Table 6-3.

DIVING TECHNIQUES AND PROCEDURES 6.4

Preparing to Dive 6.4.1 The pre-dive activities for a surface-supplied diving operation will involve many people, and include the inspection and assembling of equipment, activation of air supply systems, and dressing the divers.

A comprehensive Pre-Dive Checklist should be developed to suit the requirements of the diving unit and of the particular operation. This is in addition to the general Planning Checklist and the Safety Checklist, both of which were discussed in Chapter Four. A suggested Pre-Dive Checklist is presented in Appendix K.

Layout Gear—The first step in preparing for an actual dive—as contrasted with the planning and preparations necessary for the over-all operation—is to assemble and check all equipment. The best method for assuring that no item is overlooked is to use a carefully prepared checklist. The list should cover all items and equipments which must be on hand at the diving station including diving dress, accessories, tools, first aid supplies, decompression tables, line, shackles, spare parts and connectors for hoses and cables, and, in general, everything known to be needed or likely to be needed during the planned dive.

The diving station should be neatly organized with all diving and support equipment assigned to a specific location—and placed there. Deck space should not be cluttered with gear, and particular items of equipment which could be damaged by being stepped on should be placed out of the way (preferably off the deck). A standard layout pattern should be established and followed so that all members of the diving team will always know where to find any piece

TABLE 6-3 – LINE-PULL SIGNALS

From tender to diver

1 Pull	"Are you all right? When diver is descending, one pull means "stop."
2 Pulls	"Going down" During ascent, 2 pulls mean you have come up too far, go back down until we stop you."
3 Pulls	"Stand by to come up"
4 Pulls	"Come up"
2-1 Pulls	"I understand," or "answer the telephone"

From diver to tender

1 Pull	"I am all right" or "I am on the bottom"
2 Pulls	"Lower" or "give me slack"
3 Pulls	"Take up my slack"
4 Pulls	"Haul me up"
2-1 Pulls	"I understand" or "answer the telephone"
3-2 Pulls	"More air"
4-3 Pulls	"Less air"

Special signals from the diver

1-2-3 Pulls	"Send me a square mark"
5 Pulls	"Send me a line"
2-1-2 Pulls	"Send me a slate"

EMERGENCY SIGNALS

2-2-2 Pulls	"I am fouled and need the assistance of another diver"
3-3-3 Pulls	"I am fouled but can clear myself"
4-4-4 Pulls	"Haul me up immediately"

ALL SIGNALS WILL BE ANSWERED AS GIVEN– EXCEPT FOR EMERGENCY SIGNAL 4-4-4

Searching Signals– Without circling line

7 Pulls	"Go on (or off) searching signals"
1 Pull	"Stop and search where you are."
2 Pulls	"Move directly away from the tender if given slack, move toward the tender if strain is taken on the life line"
3 Pulls	"Go to your right"
4 Pulls	"Go to your left"

Searching Signals– With circling line

7 Pulls	Same
1 Pull	Same
2 Pulls	"Move away from the weight"
3 Pulls	"Face the weight and go right"
4 Pulls	"Face the weight and go left"

of equipment. As gear is being laid out, each item must be examined for signs of wear, rot, damage and missing components.

Activate air supply—Check the primary and secondary air supply systems and insure that competent personnel are on station to operate and stand watch over the systems. Start the air compressors of the ship's service system and check for proper operation, and check the pressure in the accumulator tanks. If high-pressure air cylinders are being used, check the manifold pressure and verify that a sufficient quantity of air is on hand for the operation. If a compressor is being used as a secondary air supply, it must be started and running throughout the dive. Verify that the air supply meets purity standards.

Check the non-return valve—Verify proper operation by attempting to blow smoke through the valve. (Re Section 6.5.1.3)

Attach air hose to air supply and helmet or mask—With air control valve closed, pressurize the hose to the planned operating pressure. Check the hose and all fittings for leaks by sound or with soapy water. Open the air control valve and allow air to flow through the helmet or mask to purge the system of any contaminants.

Attach the life-line/communications cable to the helmet, or make intercom connection to MkI mask, and test the intercom in all modes of operation.

Take depth soundings—check descending line, stage, stage lines and connections. Insure that decompression stops are properly marked.

Check the recompression chamber—insure that all necessary equipment and a copy of the recompression treatment tables are on hand, and in the chamber if appropriate. Verify the presence of two stop watches and decompression tables. Make certain that an adequate air supply is ready for immediate pressurization of the chamber and that the oxygen supply system is charged and ready for operation.

When the diving supervisor is satisfied that all equipment is on station and in good operating condition, the next step is to dress the divers. This is the responsibility of the tender. When using deep-sea gear, more than one tender or helper will be needed to assist with dressing the diver. The proper dressing procedure to be followed for each type of diving dress is presented in Figures 6-36 and 6-37.

Diving Supervisor Pre-Dive Checkout 6.4.2 The Diving Supervisor should conduct a final pre-dive checkout of the diver just before he enters the water. This checkout should cover the following points—

- briefly review the dive plan with the diver.
- verify that the divers have been properly dressed.
- with deep-sea gear, check the helmet safety lock, cotter pin, and adjustment of the jock strap.
- verify that the air control valve and the exhaust valve are adjusted for proper initial flow of air.
- test the intercom.
- verify that all necessary accessory equipment and tools for the dive are ready to be carried down by, or sent to, the diver.
- verify that the entire dive team, particularly the tenders, is ready for the dive to begin.
- verify that all of those items in the Pre-Dive Planning Checklist (Chapter Four) particularly those requiring notification of the OOD, of other ships in the vicinity, etc.—have been completed.

The diver may then move to the side and prepare to enter the water. With deep-sea gear he will be unable to walk without assistance from the tenders. The tenders should maintain a firm grip on the diver to prevent him from falling. This is best accomplished by having one tender grasp the life-line and air hose as close to the breastplate as practical while another tender grasps the goosenecks in the rear. A dressed, or partially dressed diver in deep-sea gear must never be left unattended and must never stand or move without constant tender assistance.

A All equipment is throughly inspected and laid out in an orderly manner.

Figure 6-36 Dressing Procedures, Deep-Sea Diving Outfit

B Dressed in warm clothing or woolen underwear, the diver begins to suit up.

C Two tenders assist the diver.

D The diver leans forward to properly position and fit the diving dress.

E While the diver supports himself on a bench, the tenders lace the suit.

F Properly laced suit.

G Supporting himself on the tenders, the diver steps into the weighted shoes—which the tenders strap and tie.

H With the diver seated, the breastplate is positioned. Note that the breastplate fits between the canvas suit and the rubber gasket.

I The four breastplate straps (brales) are placed over the breastplate studs—each in its specific numbered location. Note the hose ties tucked out of the way in back of the diver's neck. The lug nuts are installed hand tight.

K The diver stands, and his weight belt is fitted and positioned.

J The tender sequentially secures the lug nuts with a socket wrench.

L Final buckling and tightening is done with the diver seated. The wrist straps are put on.

M The helmet, with face plate open, is carefully lowered over the diver's head and properly aligned.

N While one tender braces the diver, the other turns the helmet until it is properly seated.

O One tender secures the dumbbell safety lock; the other begins to install the hose group.

P A tender makes final adjustments. Note hose, lifeline—cable position.

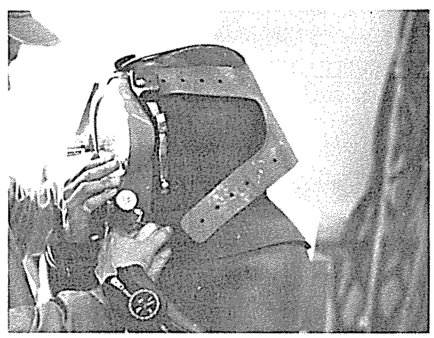
Q The diver must never be left unattended, and the tenders should frequently check his well being.

A Fully dressed in a standard wet suit (with weight belt, accessories and the lifeline tied to his waist) the diver is assisted with the Mark I Mask.

B A tender helps the diver adjust and position the mask with the air supply open.

C The mask spider is placed over the diver's head.

D The diver holds the mask in position while the tender secures the spider.



E Final adjustments are made, and the mask is secured.

F Front view of the umbilical—lifeline and air supply hose (communications line not shown).

G Side view of umbilical position.

Figure 6-37 (I) Wetsuit dressing procedures—lightweight diving

A With the diver seated, the Unisuit is loosely positioned over his head and body.

B The diver pushes his arms through the sleeves.

C He next pulls the hood over his head.

D The diver pushes his legs into the suit and tucks in the flap.

E The tender assists with the zipper which starts at the back, comes under the crotch and up the front.

Figure 6-37 (II) Unisuit dressing procedures—lightweight diving

F The diver puts on his weight belt and "come-home" bottle. Both bottle harness and weight belt are secured for quick release.

G The tender connects the mask and "come-home" bottle.

H With the mask air supply on, the tender aids the diver to pull the mask over his head.

I The diver holds the mask in position during adjustment.

J Face seal is checked and mask position adjusted.

K The tender cinches up the spider.

L The communications line is secured to the mask.

N The air supply to the suit is attached.

M A lifeline is secured around the diver's waist.

O Back view of diver prepared for pre-dive checkout.

Entering the Water 6.4.3 When entering the water by ladder, the diver must be assisted by the tenders. His movements must be slow and cautious, especially when nearing the water, to guard against being pushed or lifted off the ladder by wave action.

If entering by stage, the diver should center himself on the platform or seat and have a good grip on the bails. When standing, his feet must be apart and his legs kept straight. Upon signal from the Diving Supervisor, the winch operator and line handlers should take a strain on the stage line; then, following appropriate signals, they should lift, guide and lower the stage to the water, using the stage line and steadying lines. Visual signals for winch operators are illustrated in Table No. 6-4.

Should a diver in the lightweight outfit jump into the water, he must maintain a grip on the facemask and the tender must be sure to provide sufficient slack in the lifeline and air hose.

As the diver enters the water, he checks for leaks in his suit or air connections. The tender or another diver can be of assistance by looking for any tell-tale bubbles. A communications and time-check is made. This is the time to report any malfunctions or deficiencies not previously noted. When satisfied that he is ready in all respects to begin the dive, the diver notifies the Diving Supervisor. At this point, the tenders haul the diver over to the descending line.

If the diver must swim a short distance (although this is undesirable because of the possibilities of fatigue or CO_2 build-up) he should adjust his buoyancy so that he is floating in a vertical position with his faceplate just out of the water. When ready to move, he pushes free of the ladder or stage and swims with a dog-paddle arm stroke, using his legs in a circular pedalling motion. As he begins to move, the tender must pay out the lifeline and air hose so that the drag will not hold the diver back. If the diver tends to tip forward during swimming, the weight belt is being worn too high and the diver should be returned to the deck for proper equipment adjustment.

When in position for descent, the diver adjusts for negative buoyancy, and signals his readiness to the Diving Supervisor. If he was required to make a surface swim, he must be directed to ventilate prior to descent.

Figure 6-38 Entering the water via diving ladder

Descent 6.4.4 Descent may be accomplished with the aid of a descending line or as a passenger on the stage. By whatever method, 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 should fall.

While descending, the diver should adjust his air supply so that he breathes easily and comfortably, with a pressure balance that permits the diving dress to press closely to his body (short of squeeze) while not upsetting his stability. The diver should continue to equalize the pressure in his 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 should be halted. The difficulty may be resolved by ascending a few feet to regain a pressure balance, but if this is not effective, the diver should be returned to the surface.

Some specific instructions for descent are—

A. With a descending line, the diver locks his legs around the line and holds on to the line with one hand. The other hand will remain on the air control valve so that adjustments can quickly be made.

B. In a current or tideway, the diver should descend with his back to the flow so that he will be held against the line and not pulled away from it. If the current measures more than 1.5 knots, the diver should

Figure 6-39 Entering the water via stage

wear additional weights or descend on a weighted stage so that his descent will be as nearly vertical as possible.

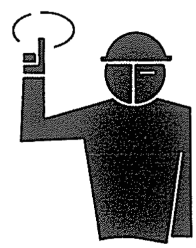
C. When the decompression stage is used for descent, it is lowered with the aid of a winch and guided to the dive-site by a shackle around the descending line. The diver stands in the center of the stage, maintaining balance by holding on to the side bails. Upon reaching the bottom, he steps back off the stage toward the same side from which he entered to avoid fouling his lines on the stage.

D. The maximum rate of descent, by any method, is 75 per feet per minute. The actual rate of descent, which may be considerably less, will be governed such factors as the diver's ability to clear his ears, by environmental conditions such as currents and reduced visibility, and the need to approach an unknown bottom with caution.

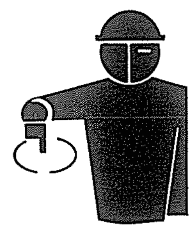
E. The diver should signal his arrival on the bottom, and quickly checks bottom conditions. If the conditions are radically different than expected, he will report his observations to the Diving Supervisor and if there is any doubt about the safety of the diver or his readiness to operate under the changed conditions, the dive should be aborted.

F. The diver should thoroughly ventilate his helmet when he arrives on the bottom and at subsequent intervals as he feels necessary and as directed from the surface.

TABLE 6-4
WINCH HAND SIGNALS

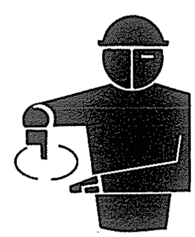


"Raise the load"

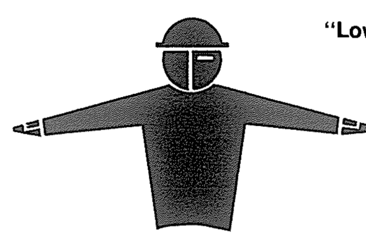


"Lower the load"

"Raise the load slowly"



"Lower the load slowly"



"Stop"

Underwater Procedures 6.4.5 Upon reaching the bottom, and before leaving the area of the stage or descending line, the diver should pause to adjust his buoyancy and to make certain that his air supply is adequate.

He should adjust his air flow to the point at which the weight of the helmet group will just be lifted from his shoulders without having lost the necessary negative buoyancy.

The diver should also check his physical condition, to satisfy himself that his helmet or mask is being properly ventilated. While standing at rest, he should feel comfortable and be breathing normally. If he is experiencing rapid breathing, panting or shortness of breath, abnormal perspiration or undue sensation of warmth, dizziness, unclear eyesight or if the helmet ports have become cloudy, there is probably an accumulation of excess CO_2 in his helmet. He should immediately increase the flow of air by simultaneously opening the air control and the exhaust valves. Proper ventilation and inflation of the deep-sea dress is usually obtained with the exhaust valve opened 2½ or 3 turns, and the air control valve adjusted accordingly.

Next, the diver must orient himself to the bottom and the work site, using such clues as the lead of the lifeline and air hose, natural features on the bottom, the direction of current and the position of the sun. He must always keep in mind, however, that bottom current may not match the surface current, and in any event, the direction of current flow and the position of the sun may change significantly during the period of the dive. If he has any trouble in determining his orientation, the tender can guide him by use of the line-pull searching signals.

The diver is now ready to move off to the work site, and to begin his assignment.

Underwater Techniques 6.4.6

MOVEMENT ON THE BOTTOM 6.4.6.1

- before leaving the descending line or stage, insure that the lifeline and air hose are not fouled with the lines.
- loop one turn of the lifeline and air hose over an arm; this will act as a buffer against a sudden surge or pull on the lines.

Figure 6-40 Correct Method for Descending on a Descending Line

- proceed slowly and cautiously, both for safety and to conserve energy.
- if obstructions are encountered, adjust buoyancy to pass over the obstruction, rather than under or around. If you must pass around an obstruction, make sure that you later return to the same side, to avoid fouling lines.
- to alter buoyancy for short periods of time without disturbing the normal adjustment of the air control and exhaust valves, the chin button inside the helmet may be used. By pushing the button with the chin, the exhaust valve will be fully opened, resulting in rapid deflation of the dress. By pulling the button with the lips, the exhaust will momentarily be shut off and rapid inflation will occur. The spitcock may also be used for regulation of the airflow.
- any adjustments to the air control valve should be made with small, cautious increments. The combined maximum discharge of the exhaust valve and the spitcock is equal to the quantity of air that will

flow through an air control valve that is only one-half open.

- the air control valve should never be completely closed, except in the event of a hose rupture or if the air hose is being replaced. The valve might become stuck in the closed position.
- if the air supply should fail or be reduced, the non-return valve will automatically be fully seated by the pressure differential. The exhaust valve and the spitcock, if open, must be immediately closed by hand.
- when using buoyancy adjustments to aid in movement, the diver must avoid "bounding" along the bottom; all movements should be controlled.
- if the current is heavy, it may be best to stoop or crawl, to reduce body area exposed to the flow. Inflation of the deep-sea dress must be adjusted to compensate for any change in depth, even if only a few feet are involved.
- moving on a rocky or coral bottom, take care that lines do not become fouled on outcroppings; guard against tripping and getting feet caught in crevices. Watch out for sharp projections which can cut hoses, diving dress or unprotected hands. The tender must be particularly careful to take up any slack in the lifeline and air hose to avoid fouling.
- on a gravel bottom, especially when walking on a slope, the diver must be on guard against slipping and falling.
- over a muddy bottom, avoid unnecessary movements so that the bottom will not be stirred up and impair visibility. If wearing a deep-sea dress, slightly increase buoyancy to keep out of the mud if possible. However, if penetrating the mud, relax and gradually work out by adjusting buoyancy and wriggling the body to break the suction of the mud. CAUTION: avoid over-inflation and be aware of the possibility of blowup when breaking loose. It may be better to call for aid from the stand-by diver than to risk blowup. One thought should be kept in mind: mud, silt or quicksand are really just "thicker water" —not solid enough to support the body, but still with greater density than water. When necessary, divers have spent many hours actually working under mud without undue problems. The primary hazard with mud bottoms comes from the concealment of obstacles and dangerous debris.

6.4.6.2 SEARCHING ON THE BOTTOM.

- the primary method for searching on the bottom is with the distance line, with the descending line as the base point of the search. The first sweep is made with the distance line held taut at a point determined by the range of visibility: the descending line should, if possible, be in sight or if visibility is near zero, within reach. The starting point should be 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 distance line another increment (roughly double the first) and makes a second sweep in the opposite direction to avoid twisting or fouling his lifeline and air hose.
- if the object is not found when the end of the distance line has been reached, the base point (the descending line) should be shifted. Each base point, in succession, should be marked by a buoy to avoid unnecessary duplication in the search. If the search becomes widespread, many of the marker buoys can be removed, leaving only those which mark the outer limits of the area.
- if the diver is unable to make a full circle around the descending line, because of excessive current or obstructions, the search pattern should be adjusted accordingly.
- a linear search pattern can be established by laying two large buoys and setting a line between them. A diving launch, with a diver on the bottom, can follow along the line from buoy to buoy, coordinating progress with the diver who is searching to each side of the base line thus established.
- once the object of a search is located, it should be marked. The diver can secure the distance line to the object as an interim measure, while waiting for a float line to be sent down.

6.4.6.3 UNUSUAL SITUATIONS

- when working around corners, where the lifeline and air hose are likely to become fouled or where line-pull signals may be dissipated, a second diver should be sent down to tend the lines of the first diver at the obstruction and pass along any line-pull signals. Such signals would be passed on the first diver's lines; the second diver would use his own lines only for signals directly pertaining to his own situation.

—when working inside a wreck, the same procedure should be followed. This technique applies to the tending divers as well: every diver who penetrates a deck level must have his own tending diver at the level—or levels—above him. Obviously, an operation requiring penetration through multiple deck levels will require detailed advance planning in order to provide for the proper support of the number of divers required.

—**enter any confined space feet first** and never force through an opening which is just barely large enough for entry.

—**when working under the bottom** of a ship, the diver should not work on the opposite side of the keel from his tender. Such movement would interfere with proper line tending. In ship repair and salvage, consideration should be given to need for special rigging and staging.

—**if working with or near lines or moorings,** some specific precautions are required—

A. Stay away from lines under strain.

B. Avoid passing under lines or moorings if at all possible; avoid brushing against lines or moorings which have been in the water long enough to become encrusted with barnacles.

C. If a line or mooring is to be shifted, the diver must be brought to the surface and, if not removed from the water, moved to a position well clear of any hazard.

D. If a diver must work with several lines—as messengers, float lines, lifting lines, etc.—each should be distinct in character (size or material) or marking (color codes, tags, wrapping).

E. NEVER CUT A LINE UNLESS IDENTIFICATION IS POSITIVE.

F. When making preparations to lift heavy weights from the bottom, the lines selected must be of sufficient strength, and the surface platform must be positioned directly over the object to be raised. Prior to the lift, the diver will leave the water.

Job Site Procedures 6.4.7 The range of jobs with which a diver may become involved is wide. Many jobs must follow detailed work procedures and may require specific pre-dive training to ensure familiarity with the work. The U. S. NAVY UNDERWATER WORK TECHNIQUES MANUAL (NAVSHIPS 0994-007-8010) presents guidance for most commonly encountered jobs—including such assignments as clearing fouled propellers, patching collision damage, replacing underwater valves or fittings, preparing for salvage of sunken vessels and recovery of heavy objects from the bottom.

For most underwater work, the diver will need to use appropriate tools. Many of these are standard hand-tools (preferably made of corrosion-resistant materials), and others are specially designed for underwater work. A qualified diver will become familiar with the particular considerations involved in working with tools underwater, whether the tool be a screwdriver or a welding torch. Hands-on training experience is the only way to get the necessary skills. In working with tools certain basic rules always apply—

A. Never use a tool that is not in good repair. If a cutting tool becomes dulled from use, it should be returned to the surface for sharpening.

B. Don't overburden the worksite with unnecessary tools, but at the same time, arrange to have all tools which may be needed, readily available.

C. Tools may be secured to the diving stage by lanyard, may be carried in a tool bag looped over the diver's right arm, or may be lowered on the descending line using a riding shackle and a light line for lowering. Power tools should be sent down ahead of the diver and should be returned to the surface before the diver makes his ascent. It is good practice to have lanyards attached to all tools, connectors, shackles, and shackle pins.

D. The diving stage itself may be used as a worksite. Such use permits organization of tools while providing for security against loss. The stage can also help give the diver leverage or stability needed when applying force (as to a wrench) or when working with a power tool which will tend to transmit a force back through the diver.

E. The diver can also obtain leverage through the use of a hogging line, tied to the work, and also to keep him in close proximity to his task without continually having to fight a current.

F. In addition to knowing how to use a variety of tools, the diver must also be experienced in the use of various materials, such as cement, foam plastic, and patching compounds. Diver training programs should, when possible, include practice in mixing and placing such materials.

EMERGENCY PROCEDURES 6.4.7.1 The subject of emergency procedures is covered in detail in Chapter Eight of this manual. However, there are a number of problems which a diver is likely to encounter in the normal range of activity which, if not promptly solved, can lead to full-scale emergencies. These problems—and the appropriate action to be taken, are—

- —loss of distance line. First, search carefully within arm's reach. If the line is not located, DO NOT enter into an area search, but inform the tender of the loss. In water less than 40 feet deep, the tender will haul in the lifeline and air hose, and attempt to guide the diver toward the descending line. The diver, coming up near the line, may make contact before too long. He should then signal "lower" to the tender, and return to his work. In water over 40 feet deep, the tender will guide the diver to the descending line with search signals.
- —fouled lines. As soon as a diver discovers that his lines have become fouled, he must stop and think. Pulling or tugging, without a plan, may only serve to increase the problem and could lead to a cut hose. The tender should be notified, if possible (the fouling may prevent transmission of line-pull signals). If the lines are fouled on some obstruction, re-tracing steps should free them. If the lines cannot be unfouled quickly and easily, the stand-by diver must be sent down to assist. He will be sent down as normal procedure should communications be interrupted and the tender not be able to haul the diver up. The stand-by diver, following down the first diver's lifeline and air hose (as a descending line), should be able to trace the foul and release the lines. If it is impossible to free the first diver, the stand-by diver will signal for a replacement lifeline and air hose.
- —If the diver becomes fouled with the descending line, and cannot easily un-foul himself, it will be 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 descending line is secured to an object, or if the weight is too heavy, the diver may have to cut the line before he can be hauled up. For this reason, a diver should normally not be permitted to descend on a line that he cannot cut. If job conditions call for use of a steel cable or a chain as a descending line, the Diving Supervisor or Diving Officer must approve of such use.
- —to replace a cut or fouled air hose. The stand-by diver first ties a lifeline around the diver's waist. He then closes the air control and exhaust valves (and spitcock if necessary), and quickly uncouples the hose coupling at the air control valve, and couples on the new hose. If the air supply in the new hose is flowing enough to form a small stream of bubbles, water will not enter the fouled diver's air system. The fouled diver should relax, and breathe easily while the change over is being made. There is enough air in the Mark V helmet to support 6 to 9 minutes of breathing.
- —After the diver is receiving air from his new hose, the stand-by diver should disconnect the lifeline/amplifier cable from the diver's helmet and replace it with the new one.
- —falling. The principal danger from falling is the sudden increase in pressure, which may not be balanced by the overbottom pressure safety factor in the air supply. Also, because of the high rate of pressure change in shallow waters, falls are more serious near the surface. For instance, a diver who falls from a stage while working on the hull of a ship, just below the surface, will be in more danger than a diver falling over an underwater cliff at 150 feet. The diver and the tender must always be alert to the possibility of a fall. When working at mid-depth in the water column, the diver should try to keep a hand on the stage or rigging. He must be careful about putting an arm over his head, however, as air may leak out around the edges of the cuffs thus changing his buoyancy and increasing the

possibility of a fall. Should a fall occur, the tender should catch the diver. When falling, the diver should try to land on his right side, if at all possible, to avoid accidental opening of the air control valve and to prevent falling on the valve in such a way that he cannot reach it with his hand.

- loss of air in a lightweight mask. The diver should head immediately for the surface. If the lines are fouled, as a last resort, he should take off the mask, ditch the weight belt, and proceed as if he were ditching an empty SCUBA.
- damage to helmet and diving dress. For a cracked faceplate the diver should keep the faceplate down and slightly increase his air pressure to prevent water leakage. For a leak in a diving suit, he need only remain in an upright position; water in the suit will not directly endanger his safety.

The best safety factors are a positive, confident attitude about diving and careful advance planning for emergencies. When a diver finds himself in trouble underwater, he should relax, avoid panic, communicate his problem with the surface and carefully think through the possible solutions to the situation. Topside support personnel should implement emergency job-site procedures as indicated. (See Chapter Four, Operations Planning and Chapter Eight, Emergencies.)

Tending the Diver 6.4.8 The tender is directly responsible for the safety of the diver. Before the dive, the tender should carefully check the diving dress, with particular attention to the exhaust valve, non-return valve, air control valve, dumbbell safety lock, intercom system, helmet gasket, breastplate studs, straps and nuts.

When the diver is ready, the tenders dress him and then assist him to the stage or ladder—always keeping a hand on the lifeline, close to the helmet, and on the goosenecks, to prevent a fall. The tender and a back-up man should always be on station to help in handling the lines. As the diver enters the water, the tender handles the lifeline and air hose. This line should be led over a bulwark or deck edge roller whenever possible and should be kept away from sharp edges. The lines should never be allowed to run free nor should they be belayed around a cleat or a set of bitts. The lifeline and air hose must be payed out at a steady rate to permit the diver to descend smoothly. The tender should handle the lines from a point at least ten feet from the descending line. If a stage is being used, the descent rate must be coordinated with the winch operator or line handlers.

Throughout the dive, the tender must keep slack out of the line while at the same time not holding it too taut. Two or three feet of slack will permit the diver freedom of movement and prevent him from being pulled off his feet by surging of the support craft or the force of any current acting on the line. The tender should, from time to time, "fish" the diver by taking in on the short slack to make sure that movement by the diver has not resulted in excessive slack. Too much slack in the line will make signaling difficult, hinder the tender from catching a fall, and increase the possibility of fouling of the lines.

The tender should monitor both the lifeline and air hose (by feel) and the descending 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 should seek an acknowledgment of condition by query signal. If the diver does not answer, the signal should be repeated and if still not answered, the Diving Supervisor should be notified and the diver should be checked over the intercom. It may be that there is

Figure 6-41 Tending the Diver around a corner

Figure 6-42 Stand-by diver and tender monitor communications from below.

too much slack in the line, or that it has become fouled, in which case the situation must be corrected. If the diver does not respond to either line-pull or voice communication, the Diving Supervisor should be notified and the stand-by diver is put into the water to investigate. At the same time the diver should be started up, depending on the circumstances.

The tender also constantly monitors the diver's progress, and keeps track of his relative position. He will do this by a number of methods—

- by following the trail of bubbles. If the diver is searching the bottom, the bubbles should move in a regular pattern; if he he is working in place, they should not shift position. If he has fallen, the bubbles may move rapidly off in a straight line.
- by feeling the pull of the lifeline and air hose.
- by watching the pneumofathometer pressure gage, to keep track of the operating depth. The gage will provide a direct reading, without the need to add air, if the diver remains at a constant depth or rises. If he descends, the hose will have to be cleared and a new reading made.
- by monitoring the gages on the supply systems for any powered equipment. For example, the ammeter on an electric welding unit will indicate a power drain when the arc is in use; the gas pressure gages for a gas torch will register 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.

Figure 6-43 Correct method of tending the diver.

- by feeling vibration in the air-power lines of pneumatic tools.

The tender assigned to the intercom system should also maintain an abbreviated circuit log (or operate a tape recorder) to record information or instructions of more than routine significance. If the intercom operator is also functioning as timekeeper, he should have the additional responsibility for making accurate log entries which will be used in the selection of decompression tables and for entry in the diver's individual records.

Ascent—6.4.9 To prepare for a normal ascent, the diver should clear the job site of tools and equipment. These can be returned to the surface by special messenger lines sent down the descending line. If the diver cannot find the descending line and needs a special line, this can be bent onto his lifeline and air hose and pulled down by the diver. He must take care not to foul the lifeline and air hose as it is laid down beside him. The tender will then pull up the slack. This technique is useful in shallow water, but not too practical in deep dives.

The diving stage, if possible, should be positioned on the bottom. If for some reason, such as fouling of the diver's lifeline and air hose around the descending line prevents sending the stage to the bottom, it should be positioned below the first decompression stop. The markers on the stage line will assist the winch operator in setting the stage; however, they are not the primary means of determining the actual decompression stops. Readings from the pneumofathometer are the primary depth measurements.

If ascent is being made using the descending line or the stage has been positioned below the first decompression stop, the tender signals the diver "stand-by to come up" when all tools and extra lines have been cleared away. The diver acknowledges the signal, increases his buoyancy slightly to ease the weight that must be hauled up, and wraps a leg around the descending line. The diver, however, does not pull himself up nor lighten himself to "float" toward the surface. The tender lifts the diver off the bottom when the diver signals "Ready to come up," and the tender signals "Coming up. Report when you leave bottom." The diver will so report.

If, during the ascent, the diver feels that he is becoming too buoyant and may be rising too quickly, he can check his ascent by clamping his legs on the descending line and adjusting his buoyancy with the exhaust valve.

The rate of ascent is a critical factor in decompressing the diver and must be carefully controlled at 60 feet per minute by the tender (25 feet per minute if using the Surface Decompression Table Using Oxygen). He can most accurately monitor the progress of the ascent with the pneumofathometer. When the diver is nearing the level of the stage, he should be warned by the tender so that he will avoid colliding with it. As he reaches the stage, he climbs aboard and notifies topside that he is "on the stage." The stage is then brought up to the first decompression stop.

Details of decompression procedure, including explanation of the tables, are presented in Chapter Seven.

In moving upward during the decompression periods, the diver must satisfy himself that he is not developing any symptoms of physical problems. If he feels any pain, dizziness, numbness, etc., he must immediately notify topside. During this often lengthy period of ascent, the diver must also check to insure that his umbilical is not becoming fouled on the stage line, the descending line, or any steadying weights hanging from the stage platform.

Upon arrival at the surface, the diver should take a firm hold on the bails of the stage and signal his readiness to the tenders. The topside personnel, timing the movement as dictated by any surface wave action, coordinate bringing the stage and the lifeline and air hose aboard.

If the diver must leave the water via ladder, the tenders must provide assistance. The diver will be tired, the gear is heavy, and a fall back into the water could result in serious injury. Under no conditions should the faceplate be opened, or any equipment removed, before the diver is firmly on deck.

Surface Decompression 6.4.10 Decompression in the water column is time consuming, uncomfortable and inhibits the ability of the support vessel to get underway, whether because of weather, threatened enemy action or to meet an operating schedule. Further, the diver cannot be provided with medical treatment if needed, and there is always the possibility of of severe chilling or accident. For these reasons, decompression is often accomplished in a surface chamber when one is installed on the support ship.

However, in transferring a diver from the water to the chamber, the tenders will be allowed no more than 3.5 minutes to undress the diver. In this time, they must remove the helmet, weighted belt and shoes. The diver may not smoke, nor can he take any smoking materials into the chamber with him. The hazards of fire, expecially if oxygen is used to facilitate decompression, are extreme. A tender, or any diving medical personnel required by the nature of the dive or the condition of the diver, must be in the chamber, with any necessary supplies, well ahead of the arrival of the diver. The time factor can be critical, and delays because of incomplete preparation cannot be tolerated. Undressing of a diver for surface decompression should be practiced until a smooth, coordinated evolution is developed.

Post Dive Procedures 6.4.11 The immediate post-dive activities of the diving team can be considered in three general areas.

SAFETY OF THE DIVER—Administer any indicated medical treatment, as for cuts or abrasions. Monitor the general condition of the diver until satisfied that no problems are likely to develop. The diver will not leave the immediate vicinity of the the diving unit, and will not be left alone, for at least six hours. The diver will not leave the general vicinity, and he definitely must not fly, for at least 12 hours.

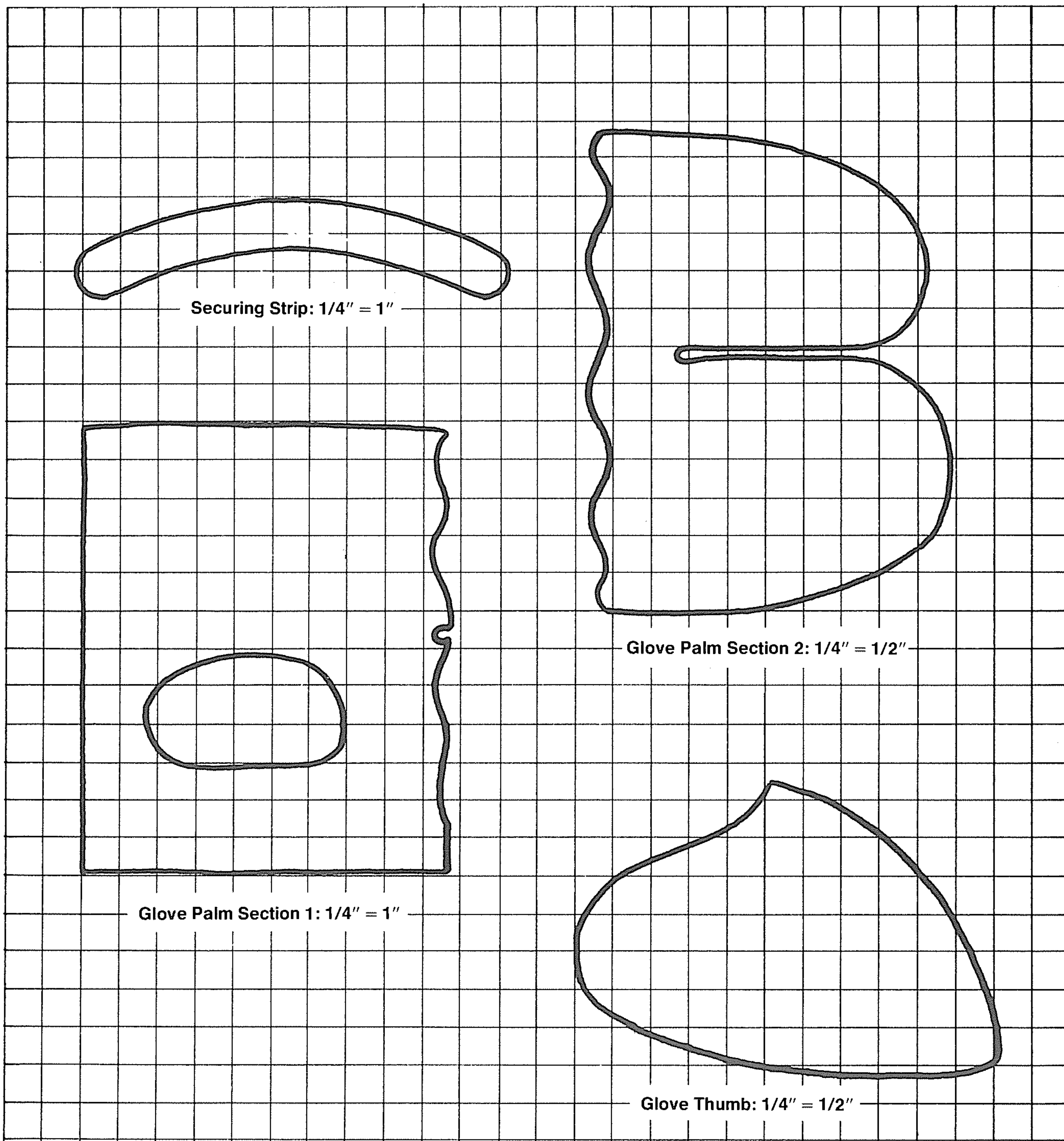


Figure 6-46 Patch patterns for cementing rubber cuffs and diver/tender gloves to the deep-sea dress

HOSE GROUP 6.5.1.3

Air Hose—

A. General condition—in good condition, without cuts, kinks or soft spots. Hose more than five years old shall not be used as diving hose, and submarine rescue vessels may not use hose more than three years old. Hose that has been stored for more than two years must be hydrostatically tested to 75% of proof pressure, or 940 psi, and held for 1 minute. When a new lot of hose has been received, one length of hose must be selected at random from the lot and hydrostatically tested to 1800 psi (75% of burst pressure). This length of hose should not, subsequently, be used for diving.

Diving hose in service, whether used for deep-sea or lightweight diving, must be tested when it is three years old, and re-tested every year (until retired from service at five years): hydrostatically test to 750 psi with a concurrent elongation load of 250 pounds applied to couplings for a duration of one minute. If a hydrostatic test cannot be made, 350 psi air pressure (with a concurrent 250 pound elongation load) may be substituted. If a length of hose must be used, and facilities are not available for the prescribed test, the hose should be subjected to an air pressure of at least two times the maximum pressure that will be applied to the hose during the dive and held for ten minutes. Hose received from any source should be accompanied by a copy of the latest test report. If hose must be used before the report has arrived, the hose must first be locally tested.

B. Pre-dive—flush new hose with fresh water and dry with oil-free air; blow air through used hose to clean. When joining lengths of hose, insert a leather washer in the female coupling. Use the best hose at the surface end where the pressure differential will be greatest.

C. Post-dive—clean and inspect hose. When a working hose has been made up and in use, moisture will be likely to accumulate in the hose. The lengths should be drained and dried before stowing.

D. To install hose fittings—

1. Slip three clamps over end of hose.
2. Coat the shank of coupling with rubber cement and clamp end in a vise. When working with a female coupling, mate it with a male unit before clamping.
3. Force the hose over the shank until tight against the shoulder of the coupling.
4. Put first clamp in position and set in vise, compressing until clamp screw holes are in line; insert screw, tighten. Repeat the procedure with the other two clamps.

Life-Line/Amplifier Cable—

A. General Condition—Check for wear within one foot of either end of cable where bending is usually maximized during use. Check for cuts, kinks and tears. Test for continuity of communication circuit.

B. Pre-dive—each length of cable is furnished with 2 male plugs (one at each end, installed), 1 double-female coupling, 1 coupling wrench, 2 leather washers (used to seal couplings or gooseneck fitting), and 1 spanner wrench (for disassembly of a plug). Cable should be made to working length, ensuring that a leather washer is at each joint. Check for continuity of the communication circuit. NOTE: when taking new cable from the cable spool allow the spool to revolve so that the cable will not twist.

C. Post-dive—Since the lifeline/amplifier cable is made-up to the air hose, it will be cleaned and dried at the same time that the air hose is being maintained, and the two will be stowed on a reel as a married unit.

D. General Maintenance—

—if a bubble forms under the outer covering, puncture with a pin, wrap with several layers of rubber tape with alternate layers of rubber cement; cover with friction tape and shellac.

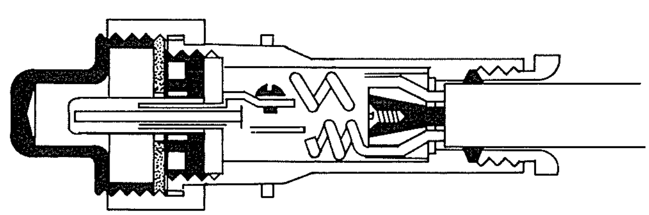


Figure 6-47 Sectional view of jack plug assembly

—re-seal any leaks or cracks in the plug seal with sealing compound or bee's wax; fill to within ¼ inch of plug.

—to remove jack plug—unscrew gland nut at the rear of the housing and remove packing; remove the lock nut at the front of plug housing (using supplied spanner wrench). Heat the housing to soften sealing compound, and slide it back on the cable. Loosen terminal connections and remove plug. Melt the solder which secures the steel core of the anchor plug, remove the screw wedge and anchor plug. The cable may now be cut back to reach undamaged wires.

—to re-assemble the jack plug—slide the gland nut and jack plug housing onto cable. Cut back and remove coverings, including inner jacket on steel cable, for four inches. Separate the strands of core, and tin. Slip the anchor plug over the cable and bring it as close as possible to the rubber covering. Spread the strands around the circumference of the plug hole and drive in the screw wedge. Solder the screw and the core cable into the anchor plug; cut off all loose ends and smooth with a file. Clean ends of the conducting wire and twist into pairs, red with green, black with white. Form an eye in end and solder. Pull plug housing down over anchor plug as far as possible. Conductors should extend about 1/4" out of the housing. Insert several turns of flax packing into the gland and screw the gland nut down tight. Place a thin leather washer over the conductors and attach them to plug terminals (red/green pair to side terminal, black/white pair to center terminal). Pour melted sealing wax into open end of the housing to within 1/4" of the plug seat; while sealing compound is still soft, seat the jack plug in the plug housing, making certain that the leather washer is properly situated on the seat. Finally screw in the locking nut and pull up tight.

To Marry Life-Line/Amplifier Cable, Air Hose and Pneumofathometer—

A. Use a block and tackle to stretch out the life-line/amplifier cable at waist height off the deck.

B. Connect the diver's air hose and pneumofathometer to an air supply and pressurize both to 150 psig. The female coupling on the air hose should be at the diver's end of the umbilical.

C. Measuring back on the life-line/amplifier cable from the jack plug, mark the cable with chalk at 20, 31 and 53 inches. Locate the diver's end of the pneumofathometer at the 20 inch mark and the diver's end of the air hose at the 31 inch mark.

D. At the 53 inch mark, take two turns around the air hose with marlin, then eight turns around the air hose, pneumofathometer and cable. Tie with a square knot between all lines.

E. Tie off in a similar manner every three feet, leaving four inches of slack in the hoses at each junction.

F. Cover 50 feet of the lifeline and air hose (from the first lashing point at the diver's end) with canvas strip 14 inches/50 feet long (folded double); sew with a herringbone stitch.

Air Control Valve—

A. General condition—all threads clean and undamaged; valve free of verdigris and dirt. Valve and valve seat cleanly ground at 60 degree angle. Packing adjusted so that the valve works stiffly but smoothly.

B. Maintenance—the valve should be periodically disassembled, cleaned and re-packed. Assembly would proceed as follows—

1. Screw the valve stem into the stuffing box.
2. Place the copper ring washer into the groove on top of the valve body.
3. Insert the valve stem into the body and screw the stuffing box up tight with a wrench. The valve stem should not be in contact with the body while the box is being drawn up tight.
4. Insert the first lead packing ring over the valve stem.
5. Take several turns around the valve stem with the flax packing, and insert the second lead packing ring.
6. Insert the stuffing box gland and screw the capnut into position.
7. The bracket is secured by screws to the valve body to prevent the capnut from backing off.
8. Place the valve handle, stem nut and cotter pin in place. Make sure that the packing is adjusted so that the valve will turn stiffly enough to prevent ac-

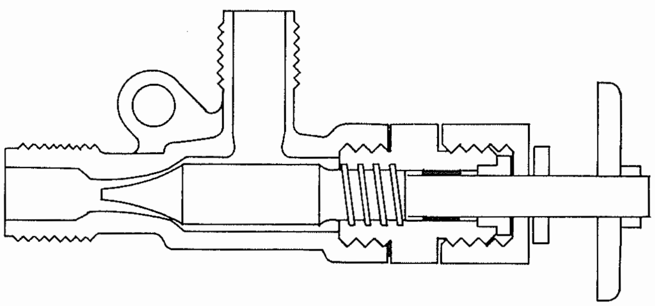


Figure 6-48 Sectional view, deep-sea air control valve

cidental changes, but smoothly and easily enough so that it can be manipulated by a diver wearing relatively clumsy diver/tender gloves.

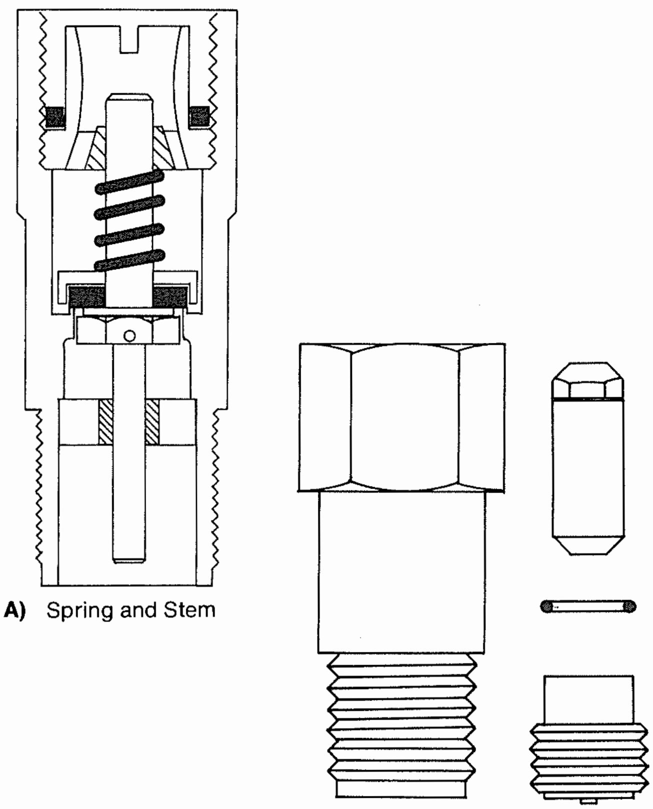
Safety Air Non-Return Valve—

A. General condition—there are two types of non-return valve, a "spring and stem" type and a "cartridge" type. Either type must be in good condition, clean, washers or "O" ring undamaged. The valves should be tested for positive closing at both high and low pressure exposure. The tests are made in the following manner—

1. High pressure—install valve backwards in an air hose and pressurized. Submerge the valve, under pressure, in a bucket of clean water and check for any signs of leaking air.
2. Low pressure—the valve must work with a pressure differential as low as the range one-half to three-quarters psi. This is a critical range, since higher pressures naturally tend to force the valve tightly against the seat. The best method for testing for low pressure operation is to blow smoke through the valve, in both directions. It should flow easily in the proper direction, and not at all in the opposite direction.

B. To repair leaking valve—in a spring and stem type, install a new leather washer and spring; in the cartridge type, install a new cartridge and "O" ring.

The cartridge valve body and insert are both marked with an arrow, to indicate the direction of flow, to assist in the installation. After re-assembling the spring and stem valve, check the inside diameter of the leather gasket to make sure that it has not spread into the air passage. This would indicate that the valve was set too tightly which could result in serious restriction of the air passage. Place the copper ring washer into the groove.



A) Spring and Stem

B) Cartridge

Figure 6-49 Sectional view of non-return valves

MISCELLANEOUS MAINTENANCE 6.5.1.4

A. Woolen items should be stored with a larvicide. Prior to use, thoroughly air or wash items.

B. Leather articles will tend to become dry and hard when used in water unless properly oiled. Neatsfoot oil should be applied in the following manner—

1. Place the item to be oiled as flat as possible.
2. Apply the oil in thin coats until the oil soaks through to the other side.
3. Do not apply oil to both sides of the material.
4. Do not submerge the item in oil.
5. When completed, wipe excess oil from the surface.

CHAPTER SEVEN

AIR DECOMPRESSION

When air is breathed under pressure, as discussed in Chapter Three, the inert nitrogen diffuses into the various tissues of the body. Nitrogen uptake by the body continues, at different rates for the various tissues, as long as the partial pressure of the inspired nitrogen is higher than the partial pressure of the gas absorbed in the tissues. Consequently, the amount of nitrogen absorbed increases with the partial pressure of the inspired nitrogen (depth) and the duration of the exposure (time).

When the diver begins to ascend, the process is reversed as the nitrogen partial pressure in the tissues exceeds that in the circulatory and respiratory systems. The pressure gradient from the tissues to the blood and lungs must be carefully controlled to prevent too rapid a diffusion of nitrogen. If the pressure gradient is uncontrolled, bubbles of nitrogen gas can form in tissues and blood which results in the development of decompression sickness.

To prevent the development of decompression sickness, special decompression tables have been established. These tables take into consideration the amount of nitrogen absorbed by the body at various depths for given time periods. They also consider allowable pressure gradients which can exist without excessive bubble formation, and the different gas elimination rates associated with various body tissues.

Stage decompression, requiring stops of specific durations at given depths, is used for air diving because of its operational simplicity. It will be found that the decompression tables require longer stops at more frequent intervals as the surface is approached due to the higher gas expansion ratios which occur at shallow depths (see page 2-16).

The USN decompression tables are the result of years of scientific study, calculation, animal and human experimentation, and extensive field experience. They represent the best overall information available, but as depth and time increases, they tend to be less accurate and require careful application. Lacking the presence of a trained Diving Medical Officer or someone otherwise qualified, the tables must be rigidly followed to ensure maximum diving safety. Variations in decompression procedures are permissible only with the guidance of a qualified diving medical officer in emergency situations.

Five different tables are discussed in this chapter and each has a unique application in air diving. Four of these tables provide specific decompression data for use under various operating conditions. The remaining table is employed in determining decompression requirements for situations in which more than one dive will be performed in a twelve-hour period.

DEFINITION OF TERMS 7.1

Those terms which are frequently used in discussions of the decompression tables are defined as follows:

Depth—when used to indicate the depth of a dive, means the maximum depth attained during the dive, measured in feet of seawater.

Bottom Time—the total elapsed time from when the diver leaves the surface in descent to the time (next whole minute) that he begins his ascent, measured in minutes.

Decompression Stop—specified depth at which a diver must remain for a specified length of time to eliminate inert gases from his body.

Decompression Schedule—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.

Single Dive—any dive conducted after 12 hours of a previous dive.

Residual Nitrogen—nitrogen gas, that is still dissolved in a diver's tissues after he has surfaced.

Surface Interval—the time which a diver has spent on the surface following a dive; beginning as soon as the diver surfaces and ending as soon as he starts his next descent.

Repetitive Dive—any dive conducted within a 12-hour period of a previous dive.

Repetitive Group Designation—a letter which relates directly to the amount of residual nitrogen in a diver's body for a 12-hour period following a dive.

Residual Nitrogen Time—an amount of time, in minutes, which must be added to the bottom time of a repetitive dive to compensate for the nitrogen still in solution in a diver's tissues from a previous dive.

Single Repetitive Dive—a dive for which the bottom time used to select the decompression schedule is the sum of the residual nitrogen time and the actual bottom time of the dive.

TABLE SELECTION 7.2

The following tables are actual decompression tables:

- Standard Air Decompression Table
- No Decompression Limits and Repetitive Group Designation Table
- Surface Decompression Table Using Oxygen
- Surface Decompression Table Using Air

They present a series of decompression schedules which must be rigidly followed during an ascent following an air dive. Each decompression table has specific conditions which justify its selection. These conditions are basically depth and duration of the dive to be conducted, availabity of a recompression chamber, availability of an oxygen breathing system within the chamber, and specific environmental conditions such as sea state, water temperature, etc.

The Residual Nitrogen Timetable for Repetitive Air Dives provides information relating to the planning of repetitive dives.

The five air tables and the pertinent criteria for the selection and application of each are listed in Table 7-1. General instructions for using the tables and special instructions applicable to each table are discussed in Sections 7.4 and 7.5 respectively.

OMITTED DECOMPRESSION 7.3

Omitted decompression is considered an emergency situation requiring recompression treatment. The subject is discussed in Chapter Eight, Section 8.5.2 Volume I of this manual.

GENERAL USE OF DECOMPRESSION TABLES 7.4

Variations in Rate of Ascent 7.4.1 With the exception of the Surface Decompression Table Using Oxygen, the rate of ascent for all dives is 60 feet per minute. If the diver is to decompress according to the

TABLE 7-1 —Air Decompression Tables Selection Criteria

TITLE	APPLICATION
U. S. Navy Standard Air Decompression Table	No locally available decompression chamber. Conditions dictate in-water decompression permissible. Normal and exceptional exposure dive schedules. Repetitive dives —normal decompression schedules only.
No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Air Dives	Decompression not required. Repetitive dives.
Residual Nitrogen Time Table for Repetitive Air Dives	Repetive Group Designations after surface intervals greater than 10 minutes and less than 12 hours. Residual Nitrogen Times for repetitive air dives.
Surface Decompression Table Using Oxygen	Available recompression chamber with oxygen breathing system. Conditions dictate in-water decompression undesirable. No repetitive dives.
Surface Decompression Table Using air	Available recompression chamber without an oxygen breathing system -or- Diver forced to surface prior to completing decompression. Conditions dictate in-water decompression undesirable. No repetitive dives.

Surface Decompression Table Using Oxygen, his rate of ascent should be 25 feet per minute. Since conditions sometimes prevent these ascent rates from being maintained, a general set of instructions has been established to compensate for any variations in rate of ascent. These instructions, along with examples of their application, are listed below:

Example No. 1—

Condition—Rate of ascent less than 60 fpm, delay occurs greater than 50 fsw.

Procedure—Increase BOTTOM TIME by the difference between the actual ascent time and the time if 60 fpm were used.

> A dive was conducted to 120 feet 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 at 30 feet. During the ascent the diver was delayed at 100 feet and it actually took 5 minutes for him to reach his 30 foot decompression stop. If an ascent rate of 60 fpm were used, it would have taken him 1 minute 30 seconds to ascend from 120 feet to 30 feet. The difference between the actual and 60 fpm ascent times is 3 minutes 30 seconds. Increase the bottom time of the dive from 60 minutes to 63 minutes 30 seconds and continue decompression according to the schedule which represents this new bottom time . . . the 120/70 schedule. (Note from the Standard Air Decompression Table that this 3 minute 30 second delay increased the diver's total decompression time from 71 minutes to 92 minutes 30 seconds—an increase of 21 minutes 30 seconds).

Example No. 2—

Condition—Rate of ascent less than 60 fpm delay occurs less than 50 fsw.

Procedure—Increase TIME OF FIRST DECOMPRESSION STOP by difference between the actual ascent time and the time if 60 fpm were used.

> A dive was conducted to 120 feet with a bottom time of 60 minutes. From the Standard Air Decompression Table the first decompression stop is at 30 fsw. During the ascent, the diver was delayed at 40 feet and it actually took 5 minutes for him to reach his 30-foot stop. As in the preceding example, the correct ascent time should have been 1 minute 30 seconds causing a delay of 3 minutes 30 seconds. Increase the length of the 30 foot decompression stop by 3 minutes 30 seconds. Instead of 2 minutes, the diver must spend 5 minutes 30 seconds at 30 feet. (Note that in this example, the diver's total decompression time is increased by only 7 minutes; the 3 minute 30 second delay in ascent plus the additional 3 minutes 30 seconds he had to spend at 30 feet).

Example No. 3—

Condition—Rate of ascent greater than 60 fpm, no decompression required, bottom time places the diver within 10 minutes of decompression schedule requiring decompression.

Procedure—Stop at 10 feet for the time that it would have taken to ascend at a rate of 60 fpm.

> A dive was conducted to 100 feet with a bottom time of 22 minutes. During ascent, the diver momentarily lost control of his buoyancy and increased his ascent rate to 75 fpm. Normally, the 100/25 decompression schedule of the Standard Air Decompression Table would be used, which is a no-decompression schedule. However, the actual bottom time of 22 minutes is within 10 minutes of the 100/30 dive schedule which does require decompression. The diver must stop at 10 feet and remain there for 1 minute and 40 seconds, the time that it would have taken him to ascend at 60 fpm.

Example No. 4—

Condition—Rate of ascent greater than 60 fpm, decompression required.

Procedure—Stop 10 feet below the first decompression stop for the remaining time that it would have taken if a rate of 60 fpm were used.

A diver ascending from a 120/50 scheduled dive takes only 30 seconds to reach his 20-foot decompression stop. At a rate of 60 fpm his ascent time should have been 1 minute 40 seconds. He must return to 30 feet and remain there for the difference between 1 minute 40 seconds and 30 seconds, or 1 minute 10 seconds.

The rate of ascent between stops is not critical, and variations from the specified rate require no compensation.

Selection of Decompression Schedule 7.4.2 The decompression schedules of all the tables are given in 10 or 20-foot depth increments and, usually, 10-minute bottom time increments. Depth and bottom time combinations from actual dives, however, rarely exactly match one of the decompression schedules listed in the table being used. As assurance that the selected decompression schedule is always conservative—(A) always select the schedule depth to be equal to or the next depth greater than the actual depth to which the dive was conducted, and (B) always select the schedule bottom time to be equal to or the next longer bottom time than the actual bottom time of the dive.

If the Standard Air Decompression Table, for example, was being used to select the correct schedule for a dive to 97 feet for 31 minutes, decompression would be carried out in accordance with the 100/40 schedule.

NEVER ATTEMPT TO INTERPOLATE BETWEEN DECOMPRESSION SCHEDULES

If the diver was exceptionally cold during the dive, or if his work load was relatively strenuous, the next longer decompression schedule than the one he would normally follow should be selected. For example, the normal schedule for a dive to 90 feet for 34 minutes would be the 90/40 schedule. If the diver were exceptionally cold or fatigued, he should decompress according to the 90/50 schedule.

Rules During Ascent 7.4.3 After the correct decompression schedule has been selected, it is imperative that it be exactly followed. Without exception, decompression must be completed according to the selected schedule unless the directions to alter the schedule are given by a diving medical officer.

Ascend at a rate of 60 feet per minute when using all tables except the Surface Decompression Table Using Oxygen. This table uses a rate of 25 feet per minute. Any variation in the rate of ascent must be corrected in accordance with the earlier instructions. The diver's chest should be located as close as possible to the stop depth. A pneumofathometer is the most practical instrument for ensuring proper measurement.

The decompression stop times, as specified in each decompression schedule, begin as soon as the diver reaches the stop depth. Upon completion of the specified stop time, the diver ascends to the next stop, or to the surface, at the proper ascent rate. DO NOT INCLUDE ASCENT TIME AS PART OF STOP TIME.

Exceptional Exposure 7.4.4 The exceptional exposure air decompression schedules presented in the Standard Air Decompression Table are for dives which expose the diver to oxygen partial pressures and environmental conditions considered extreme by Navy standards. The prolonged decompressions, which must be carried out in the water, impose exceptional demands on the diver's endurance. Because of this, decompressions conducted according to these schedules have limited assurance that they will be completed without an incidence of decompression sickness. For this reason, the Diving Officer must fully justify the need for conducting an exceptional exposure dive.

Repetitive Dives 7.4.5 During the 12-hour period after an air dive, the quantity of residual nitrogen in a diver's body will gradually reduce to its normal level. If, within this period, the diver is to make a second dive—called a repetitive dive—he must consider his present residual nitrogen level when planning for the dive.

The procedures for conducting a repetitive dive are summarized in Figure 7-1. Upon completing his first dive, the diver will have a Repetitive Group Designation assigned to him by either the Standard Air Table or the No-Decompression Table. This designation relates directly to his residual nitrogen level upon surfacing. As nitrogen passes out of his tissues and blood, his repetitive group designation changes. The Residual Nitrogen Table permits this designation to be determined at any time during the surface interval.

Just prior to beginning the repetitive dive, the residual nitrogen time should be determined using the Residual Nitrogen Table. This time is added to the actual bottom time of the respective dive to give the bottom time of the **equivalent single dive**. Decompression from the repetitive dive is conducted using the depth and bottom time of the equivalent single dive to select the appropriate decompression schedule. Equivalent single dives which require the use of exceptional exposure decompression schedules should, whenever possible, be avoided.

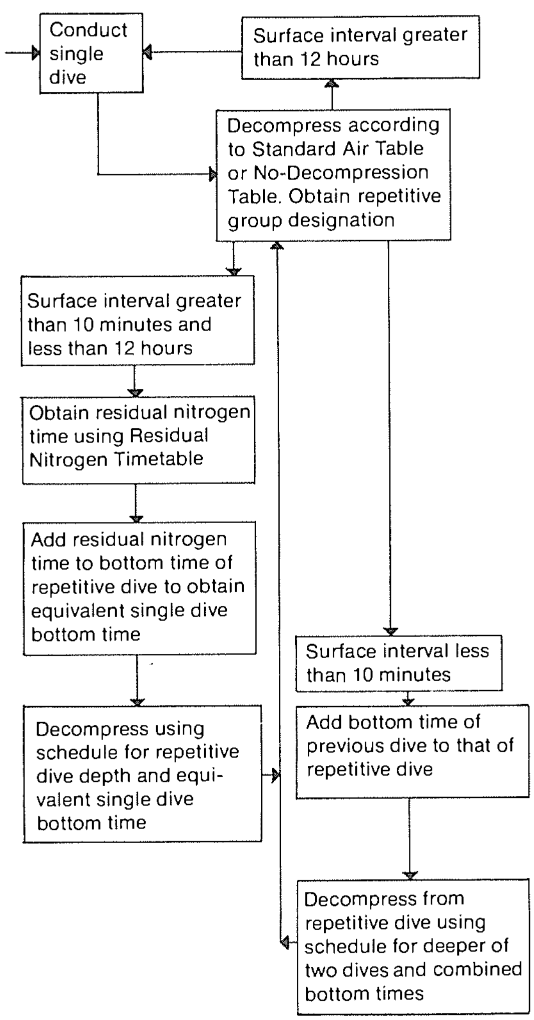


Figure 7-1 Repetitive Dive Flowchart

To assist in determining the decompression schedule for a repetitive dive, a systematic repetitive dive worksheet, shown in Figure 7-2, should always be used.

If still another dive is to follow the repetitive dive, the depth and bottom time of the first equivalent single dive should be inserted in part I of the second repetitive dive worksheet.

Surface Decompression 7.4.6 Surface decompression is a technique for fulfilling all or a portion, of the diver's decompression obligation in a recompression chamber. By using this technique, the time which the diver must spend in the water is significantly reduced, and when oxygen is breathed in the recompression chamber, the diver's total decompression time is reduced.

Surface decompression offers many advantages, most of which enhance the diver's safety. Shorter exposure time to the water keeps him from chilling to a dangerous level. Inside the recompression chamber, he can be maintained at a constant pressure, unaffected by surface conditions of the sea. Observed constantly by the chamber operator, and monitored intermittently by medical personnel, any signs of decompression sickness can be readily detected and immediately treated.

If an oxygen breathing system is installed in the recompression chamber, surface decompression should be conducted according to the Surface Decompression Table Using Oxygen. If air is the only breathing medium available, the Surface Decompression Table Using Air must be used.

There is no surface decompression table for use following an exceptional exposure dive. Additionally, repetitive diving tables for dives following surface decompression have not been calculated.

Dive Recording 7.4.7 Appendix B provides information for maintaining a diving log and for reporting individual dives to the U. S. Navy Safety Center. In addition to these records, every Navy dive should be recorded on a diving chart, similar to the one

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

_____ minutes ☐ Standard Air Table

_____ feet ☐ No-Decompression Tab.

_____ repetitive group designation

II. SURFACE INTERVAL:

_____ hours _____ minutes on surface.

Repetitive group from I _____

New repetitive group from surface

Residual Nitrogen Timetable _____

III. RESIDUAL NITROGEN TIME:

_____ feet (depth of repetitive dive)

New repetitive group from II. _____

Residual nitrogen time from

Residual Nitrogen Timetable _____

IV. EQUIVALENT SINGLE DIVE TIME:

_____ minutes, residual nitrogen time from III.

+ _____ minutes, actual bottom time of repetitive dive.

= _____ minutes, equivalent single dive time.

V. DECOMPRESSION FOR REPETITIVE DIVE:

_____ minutes, equivalent single dive time from IV.

_____ feet, depth of repetitive dive

Decompression from (check one):
☐ Standard Air Table ☐ No-Decompression Table
☐ Surface Table Using Oxygen ☐ Surface Table Using Air
☐ No decompression required

Decompression Stops: _____ feet _____ minutes
_____ feet _____ minutes
_____ feet _____ minutes
_____ feet _____ minutes
_____ feet _____ minutes

Schedule used _____

Repetitive group _____

Figure 7-2 Repetitive Dive Worksheet

NAME OF DIVER	RATE	TABLE USED	DATE
NAME OF DIVER	RATE	TENDER (Sign name)	
PURPOSE OF DIVE			

LEFT SURFACE	REACHED BOTTOM	DESCENT TIME	LEFT BOTTOM	TIME TO FIRST STOP	TOTAL BOTTOM TIME
DEPTH IN FEET	PRESSURE IN POUNDS		TOTAL DECOMPRESSION TIME		TOTAL TIME OF DIVE

DIVE RECORD	DEPTH OF STOP	LBS. PRESSURE	TIME
	130	58	REACHED LEFT
	120	54	REACHED LEFT
	110	49	REACHED LEFT
	100	44.5	REACHED LEFT
	90	40	REACHED LEFT
	80	36	REACHED LEFT
	70	32	REACHED LEFT
	60	27	REACHED LEFT
	50	22	REACHED LEFT
	40	18	REACHED LEFT
	30	13	REACHED LEFT
	20	9	REACHED LEFT
	10	4.5	REACHED LEFT
REACHED SURFACE	DIVER'S CONDITION		
NEW GROUP	REMARKS		

Figure 7-3 Diving Chart

shown in Figure 7-3. The diving chart is strictly a convenient means of collecting the dive data, which in turn, will be copied in the official dive log. Use of the chart will be shown in the examples given in later sections of this chapter.

AIR DECOMPRESSION TABLES—7.5

U.S. Navy Standard Air Decompression Table

7.5.1 This manual has combined the Standard Air Table and the Exceptional Exposure Air Table into one table as titled above. To clearly delineate between the standard and exceptional exposure decompression schedules, the exceptional exposure schedules have been printed in RED.

The USN decompression tables are the result of years of scientific study, calculation, animal and human experimentation, and extensive field experience. They represent the best overall information available, but as depth and time increases, they tend to be less accurate and require careful application. Lacking the presence of a trained Diving Medical Officer or someone otherwise qualified, the tables must be rigidly followed to ensure maximum diving safety. Variations in decompression procedures are permissible only with the guidance of a qualified diving medical officer in emergency situations.

Figure 7-4 Deep-sea divers undergoing in-water decompression.

These limits are not to be exceeded without the approval of the Diving Officer in charge of the operation, and then, only after careful consideration of the potential consequences involved.

If the bottom time of a dive is less than the first bottom time listed for its depth, decompression is not required. The diver may ascend directly to the surface at a rate of 60 feet per minute. The repetitive group designation for no-decompression dives is given in the No-Decompression Table.

As will be noted in the Standard Air Table, there are no repetitive group designations for exceptional exposure dives. Repetitive dives following an exceptional exposure dive are not permitted.

Example—

Problem—Diver Bowman has just completed a salvage dive to a depth of 143 feet for 37 minutes. He was not exceptionally cold or fatigued during the dive. What is his decompression schedule and his repetitive group designation at the end of the decompression?

Solution—Select the equal or next deeper and the equal or next longer decompression schedule. This would be the 150/40 schedule.

ACTION	TIME (min:sec)	TOTAL ELAPSED ASCENT TIME (min:sec)
Ascend to 30 feet at 60 fpm	1:53	1:53
Remain at 30 feet	5:00	6:53
Ascend to 20 feet	0:10	7:03
Remain at 20 feet	19:00	26:03
Ascend to 10 feet	0:10	26:13
Remain at 10 feet	33:00	59:13
Ascend to surface	0:10	59:23

Repetitive Group Designation "N"

U. S· NAVY STANDARD AIR DECOMPRESSION TABLE

Depth (feet)	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet) 50	40	30	20	10	Total ascent (min:sec)	Repetitive group
40	200						0	0:40	*
	210	0:30					2	2:40	N
	230	0:30					7	7:40	N
	250	0:30					11	11:40	O
	270	0:30					15	15:40	O
	300	0:30					19	19:40	Z
	360	0:30					23	23:40	**
	480	0:30					41	41:40	**
	720	0:30					69	69:40	**
50	100						0	0:50	*
	110	0:40					3	3:50	L
	120	0:40					5	5:50	M
	140	0:40					10	10:50	M
	160	0:40					21	21:50	N
	180	0:40					29	29:50	O
	200	0:40					35	35:50	O
	220	0:40					40	40:50	Z
	240	0:40					47	47:50	Z
60	60						0	1:00	*
	70	0:50					2	3:00	K
	80	0:50					7	8:00	L
	100	0:50					14	15:00	M
	120	0:50					26	27:00	N
	140	0:50					39	40:00	O
	160	0:50					48	49:00	Z
	180	0:50					56	57:00	Z
	200	0:40				1	69	71:00	Z
	240	0:40				2	79	82:00	**
	360	0:40				20	119	140:00	**
	480	0:40				44	148	193:00	**
	720	0:40				78	187	266:00	**
70	50						0	1:10	*
	60	1:00					8	9:10	K
	70	1:00					14	15:10	L
	80	1:00					18	19:10	M
	90	1:00					23	24:10	N
	100	1:00					33	34:10	N
	110	0:50				2	41	44:10	O
	120	0:50				4	47	52:10	O
	130	0:50				6	52	59:10	O
	140	0:50				8	56	65:10	Z
	150	0:50				9	61	71:10	Z
	160	0:50				13	72	86:10	Z
	170	0:50				19	79	99:10	Z

*** See No Decompression Table for repetitive groups**
****Repetitive dives may not follow exceptional exposure dives**

U. S NAVY STANDARD AIR DECOMPRESSION TABLE

Depth (feet)	Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet) 50	40	30	20	10	Total ascent (min:sec)	Repetitive group
80	40						0	1:20	*
	50	1:10					10	11:20	K
	60	1:10					17	18:20	L
	70	1:10					23	24:20	M
	80	1:00				2	31	34:20	N
	90	1:00				7	39	47:20	N
	100	1:00				11	46	58:20	O
	110	1:00				13	53	67:20	O
	120	1:00				17	56	74:20	Z
	130	1:00				19	63	83:20	Z
	140	1:00				26	69	96:20	Z
	150	1:00				32	77	110:20	Z
	180	1:00				35	85	121:20	**
	240	0:50			6	52	120	179:20	**
	360	0:50			29	90	160	280:20	**
	480	0:50			59	107	187	354:20	**
	720	0:40		17	108	142	187	455:20	**
90	30						0	1:30	*
	40	1:20					7	8:30	J
	50	1:20					18	19:30	L
	60	1:20					25	26:30	M
	70	1:10				7	30	38:30	N
	80	1:10				13	40	54:30	N
	90	1:10				18	48	67:30	O
	100	1:10				21	54	76:30	Z
	110	1:10				24	61	86:30	Z
	120	1:10				32	68	101:30	Z
	130	1:00			5	36	74	116:30	Z
100	25						0	1:40	*
	30	1:30					3	4:40	I
	40	1:30					15	16:40	K
	50	1:20				2	24	27:40	L
	60	1:20				9	28	38:40	N
	70	1:20				17	39	57:40	O
	80	1:20				23	48	72:40	O
	90	1:10			3	23	57	84:40	Z
	100	1:10			7	23	66	97:40	Z
	110	1:10			10	34	72	117:40	Z
	120	1:10			12	41	78	132:40	Z
	180	1:00		1	29	53	118	202:40	**
	240	1:00		14	42	84	142	283:40	**
	360	0:50	2	42	73	111	187	416:40	**
	480	0:50	21	61	91	142	187	503:40	**
	720	0:50	55	106	122	142	187	613:40	**
110	20						0	1:50	*
	25	1:40					3	4:50	H
	30	1:40					7	8:50	J
	40	1:30				2	21	24:50	L
	50	1:30				8	26	35:50	M
	60	1:30				18	36	55:50	N
	70	1:20			1	23	48	73:50	O
	80	1:20			7	23	57	88:50	Z
	90	1:20			12	30	64	107:50	Z
	100	1:20			15	37	72	125:50	Z

*** See No Decompression Table for repetitive groups**
****Repetitive dives may not follow exceptional exposure dives**

U. S NAVY STANDARD AIR DECOMPRESSION TABLE

Depth (feet)	Bottom time (min)	Time to first stop (min: sec)	110	100	90	80	70	60	50	40	30	20	10	Total ascent (min: sec)	Repetitive group
			Decompression stops (feet)												
190	5												0	3:10	D
	10	2:50										1	3	7:10	G
	15	2:50										4	7	14:10	I
	20	2:40									2	6	20	31:10	K
	25	2:40									5	11	25	44:10	M
	30	2:30								1	8	19	43	63:10	N
	40	2:30								8	14	23	55	103:10	O
	50	2:20							4	13	22	33	72	147:10	Z
	60	2:20							10	17	19	50	84	183:10	Z

Depth (feet)	Bottom time (min)	Time to first stop (min:sec)	130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent (min:sec)
			Decompression stops (feet)													
200	5	3:10													1	4:20
	10	3:00												1	4	8:20
	15	2:50											1	4	10	18:20
	20	2:50											3	7	27	40:20
	25	2:50											7	14	25	49:20
	30	2:40										2	9	22	37	73:20
	40	2:30									2	8	17	23	59	112:20
	50	2:30									6	16	22	39	75	161:20
	60	2:20								2	13	17	24	51	89	199:20
	90	1:50					1	10	10	12	12	30	38	74	134	324:20
	120	1:40				6	10	10	10	24	28	40	64	98	180	473:20
	180	1:20		1	10	10	18	24	24	42	48	70	106	142	187	685:20
	240	1:20		6	20	24	24	36	42	54	68	114	122	142	187	842:20
	360	1:10	12	22	36	40	44	56	82	98	100	114	122	142	187	1058:20
210	5	3:20													1	4:30
	10	3:10												2	4	9:30
	15	3:00											1	5	13	22:30
	20	3:00											4	10	23	40:30
	25	2:50										2	7	17	27	56:30
	30	2:50										4	9	24	41	81:30
	40	2:40									4	9	19	26	63	124:30
	50	2:30								1	9	17	19	45	80	174:30
220	5	3:30													2	5:40
	10	3:20												2	5	10:40
	15	3:10											2	5	16	26:40
	20	3:00										1	3	11	24	42:40
	25	3:00										3	8	19	33	66:40
	30	2:50									1	7	10	23	47	91:40
	40	2:50									6	12	22	29	68	140:40
	50	2:40								3	12	17	18	51	86	190:40

U. S. NAVY STANDARD AIR DECOMPRESSION TABLE

Depth (feet)	Bottom time (min)	Time to first stop (min:sec)	130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent time (min:sec)
			Decompression stops (feet)													
230	5	3:40													2	5:50
	10	3:20											1	2	6	12:50
	15	3:20											3	6	18	30:50
	20	3:10										2	5	12	26	48:50
	25	3:10										4	8	22	37	74:50
	30	3:00									2	8	12	23	51	99:50
	40	2:50								1	7	15	22	34	74	156:50
	50	2:50								5	14	16	24	51	89	202:50
240	5	3:50													2	6:00
	10	3:30											1	3	6	14:00
	15	3:30											4	6	21	35:00
	20	3:20										3	6	15	25	53:00
	25	3:10									1	4	9	24	40	82:00
	30	3:10									4	8	15	22	56	109:00
	40	3:00								3	7	17	22	39	75	167:00
	50	2:50							1	8	15	16	29	51	94	218:00
250	5	3:50												1	2	7:10
	10	3:40											1	4	7	16:10
	15	3:30										1	4	7	22	38:10
	20	3:30										4	7	17	27	59:10
	25	3:20									2	7	10	24	45	92:10
	30	3:20									6	7	17	23	59	116:10
	40	3:10								5	9	17	19	45	79	178:10
	60	2:40					4	10	10	10	12	22	36	64	126	298:10
	90	2:10		8	10	10	10	10	10	28	28	44	68	98	186	514:10
260	5	4:00												1	2	7:20
	10	3:50											2	4	9	19:20
	15	3:40										2	4	10	22	42:20
	20	3:30									1	4	7	20	31	67:20
	25	3:30									3	8	11	23	50	99:20
	30	3:20								2	6	8	19	26	61	126:20
	40	3:10							1	6	11	16	19	49	84	190:20
270	5	4:10												1	3	8:30
	10	4:00											2	5	11	22:30
	15	3:50										3	4	11	24	46:30
	20	3:40									2	3	9	21	35	74:30
	25	3:30								2	3	8	13	23	53	106:30
	30	3:30								3	6	12	22	27	64	138:30
	40	3:20							5	6	11	17	22	51	88	204:30

U. S. NAVY STANDARD AIR DECOMPRESSION TABLE

Depth (feet)	Bottom time (min)	Time to first stop (min:sec)	130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent time (min:sec)
			Decompression stops (feet)													
280	5	4:20												2	2	8:40
	10	4:00										1	2	5	13	25:40
	15	3:50									1	3	4	11	26	49:40
	20	3:50									3	4	8	23	39	81:40
	25	3:40								2	5	7	16	23	56	113:40
	30	3:30							1	3	7	13	22	30	70	150:40
	40	3:20						1	6	6	13	17	27	51	93	218:40
290	5	4:30												2	3	9:50
	10	4:10										1	3	5	16	29:50
	15	4:00									1	3	6	12	26	52:50
	20	4:00									3	7	9	23	43	89:50
	25	3:50								3	5	8	17	23	60	120:50
	30	3:40							1	5	6	16	22	36	72	162:50
	40	3:30						3	5	7	15	16	32	51	95	228:50
300	5	4:40												3	3	11:00
	10	4:20										1	3	6	17	32:00
	15	4:10									2	3	6	15	26	57:00
	20	4:00								2	3	7	10	23	47	97:00
	25	3:50							1	3	6	8	19	26	61	129:00
	30	3:50							2	5	7	17	22	39	75	172:00
	40	3:40						4	6	9	15	17	34	51	90	231:00
	60	3:00		4	10	10	10	10	10	14	28	32	50	90	187	460:00

Extreme exposures—250 and 300 ft

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent time (min:sec)
			Decompression stops (feet)																				
250	120	1:50							5	10	10	10	10	16	24	24	36	48	64	94	142	187	684:10
	180	1:30					4	8	8	10	22	24	24	32	42	44	60	84	114	122	142	187	931:10
	240	1:30					9	14	21	22	22	40	40	42	56	76	98	100	114	122	142	187	1109:10
300	90	2:20					3	8	8	10	10	10	10	16	24	24	34	48	64	90	142	187	693:00
	120	2:00			4	8	8	8	8	10	14	24	24	24	34	42	58	66	102	122	142	187	890:00
	180	1:40	6	8	8	8	14	20	21	21	28	40	40	48	56	82	98	100	114	122	142	187	1168:00

No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Air Dives 7.5.2 The No-Decompression Table serves two purposes. First it summarizes all the depth and bottom time combinations for which no decompression is required. Secondly, it provides the repetitive group designation for each no-decompression dive. Even though decompression is not required, an amount of nitrogen remains in the diver's tissues after every dive. If he dives again within a 12 hour period, the diver must consider this residual nitrogen when calculating his decompression.

Each depth listed in the No-Decompression Table has a corresponding **no-decompression limit** given in minutes. This limit is the maximum bottom time that a diver may spend at that depth without requiring decompression. The columns to the right of the no-decompression limits column are used to determine the repetitive group designation which must be assigned to a diver subsequent to every dive. To find the repetitive group designation enter the table at the depth equal to or next greater than the actual depth of the dive. Follow that row to the right to the bottom time equal to or next greater than the actual bottom time of the dive. Follow that column upward to the repetitive group designation.

Depths above 35 feet do not have a specific no-decompression limit. They are, however, restricted in that they only provide repetitive group designations for bottom times up to between 5 and 6 hours. These bottom times are considered the limitations of the No-Decompression Table and no field requirement for diving should extend beyond them.

Any dive below 35 feet which has a bottom time greater than the no-decompression limit given in this table is a decompression dive and should be conducted in accordance with the Standard Air Table.

Example—

Problem—In planning a dive, the Master Diver wants to conduct a brief inspection of the work site, located 160 feet below the surface. What is the maximum bottom time which he may use without requiring decompression? What is his repetitive group designation after the dive?

Solution—The no-decompression limit corresponding to the 160 foot depth in the No-Decompression Table is 5 minutes. Therefore, the Master Diver must descend to 160 feet, make his inspection and begin his ascent within 5 minutes without having to undergo decompression.

Following the 160 foot depth row to the 5 minute column, the repetitive group designation at the top of this column is D.

NO-DECOMPRESSION LIMITS AND REPETITIVE GROUP DESIGNATION TABLE FOR NO-DECOMPRESSION AIR DIVES

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

Residual Nitrogen Timetable for Repetitive Air Dives 7.3.5 The quantity of residual nitrogen in a diver's body immediately after a dive is expressed by the repetitive group designation assigned to him by either the Standard Air Table or the No-Decompression Table. The upper portion of the Residual Nitrogen Table is composed of various intervals between 10 minutes and 12 hours, expressed in minutes: hours (2:21 = 2 hours 21 minutes). Each interval has two limits; 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, 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. The time spent on the surface must be between or equal to the limits of the selected interval.

Next, read vertically downwards to the new repetitive group designation. This designation corresponds to the present quantity of residual nitrogen in the diver's body. Continue downward in this same column to the row which represents the depth of the repetitive dive. The time given at the intersection is the residual nitrogen time, in minutes, to be applied to the repetitive dive.

If the surface interval is less than 10 minutes, the residual nitrogen time is the bottom time of the previous dive. All of the residual nitrogen will be passed out of the diver's body after 12 hours, so a dive conducted after a 12 hour surface interval is not a repetitive dive.

There is one exception to this table. In some instances, when the repetitive dive is to the same or greater depth than the previous dive, the residual nitrogen time may be longer than the actual bottom time of the previous dive. In this event, add the actual bottom time of the previous dive to the actual bottom time of the repetitive dive to obtain the equivalent single dive time.

Example—

Problem—A repetitive dive is to be made to 98 fsw for an estimated bottom time of 15 minutes. The previous dive was to a depth of 102 fsw and had a 48 minute bottom time. The diver's surface interval is 6 hours 28 minutes (6:38). What decompression schedule should be used for the repetitive dive?

Solution—Using the repetitive dive worksheet—

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

48 minutes ☑ Standard Air Table

102 feet ☐ No-Decompression Table

M repetitive group designation

II. SURFACE INTERVAL:

6 hours 28 minutes on surface.

Repetitive group from I M

New repetitive group from surface

Residual Nitrogen Timetable B

III. RESIDUAL NITROGEN TIME:

98 feet (depth of repetitive dive)

New repetitive group from II. B

Residual nitrogen time from

Residual Nitrogen Timetable 7

IV. EQUIVALENT SINGLE DIVE TIME:

7 minutes, residual nitrogen time from III.

+15 minutes, actual bottom time of repetitive dive.

=22 minutes, equivalent single dive time.

V. DECOMPRESSION FOR REPETITIVE DIVE:

22 minutes, equivalent single dive time from IV.

98 feet, depth of repetitive dive

Decompression from (check one):
☐ Standard Air Table ☐ No-Decompression Table
☐ Surface Table Using Oxygen ☐ Surface Table Using Air
☑ No decompression required

Decompression Stops: ____ feet ____ minutes

____ feet ____ minutes

____ feet ____ minutes

____ feet ____ minutes

____ feet ____ minutes

Schedule used ____

Repetitive group ____

RESIDUAL NITROGEN TIMETABLE FOR REPETITIVE AIR DIVES

*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.

Repetitive group at the beginning of the surface interval																
A																0:10 12:00*
B															0:10 2:10	2:11 12:00*
C														0:10 1:39	1:40 2:49	2:50 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 3:22	3:23 6:32	6:33 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 8:40	8:41 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 1:39	1:40 2:05	2:06 2:34	2:35 3:08	3:09 3:52	3:53 4:49	4:50 6:18	6:19 9:28	9:29 12:00*
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*
	0:10 0:22	0:23 0:34	0:35 0:48	0:49 1:02	1:03 1:18	1:19 1:36	1:37 1:55	1:56 2:17	2:18 2:42	2:43 3:10	3:11 3:45	3:46 4:29	4:30 5:27	5:28 6:56	6:57 10:05	10:06 12:00*
NEW → GROUP DESIGNATION	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A

REPETITIVE DIVE DEPTH	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
40	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
60	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	3
100	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3
130	46	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3
140	42	40	38	35	32	29	26	23	20	18	15	12	10	7	5	2
150	40	38	35	32	30	27	24	22	19	17	14	12	9	7	5	2
160	37	36	33	31	28	26	23	20	18	16	13	11	9	6	4	2
170	35	34	31	29	26	24	22	19	17	15	13	10	8	6	4	2
180	32	31	29	27	25	22	20	18	16	14	12	10	8	6	4	2
190	31	30	28	26	24	21	19	17	15	13	11	10	8	6	4	2

RESIDUAL NITROGEN TIMES (MINUTES)

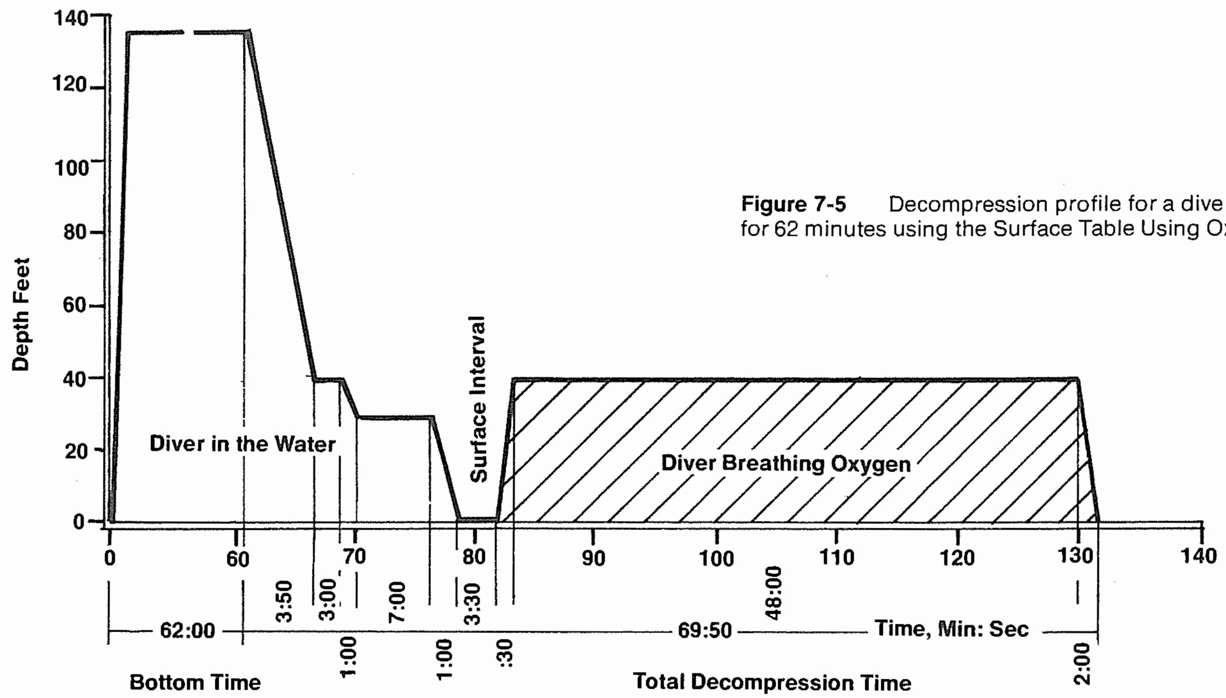


Figure 7-5 Decompression profile for a dive to 136 feet for 62 minutes using the Surface Table Using Oxygen

Surface Decompression Table Using Oxygen 7.5.4

The application of the Surface Table Using Oxygen requires a recompression chamber with an oxygen breathing system as described in Section 8.4.3 (Chapter Eight).

The ascent rate to the first decompression stop, or to the surface if no stops are required, is 25 feet per minute. The ascent time between each stop, and from the 30 foot stop to the surface, is 1 minute.

Once the diver is on the surface, his tenders must remove his breathing apparatus and his weight belt and assist him into the recompression chamber within 3½ minutes. Pressurization of the chamber with air should take about 30 seconds. This means that the total elapsed time from when the diver leaves the 30 foot water depth to when he reaches the 40 foot recompression depth **must not exceed 5 minutes.**

As soon as the diver enters the chamber he must begin breathing pure oxygen via an approved mask breathing system. He is to remain on oxygen down to and throughout the designated 40 foot stop time. While the diver is breathing oxygen, the chamber must be ventilated as prescribed in Section 8.4.3.4.

Upon completion of the designated 40 foot chamber stop, the chamber should be depressurized to atmospheric pressure at a constant rate over a 2 minute period. During ascent, the diver is to remain on oxygen.

Should the diver develop oxygen toxicity problems, or the oxygen breathing system fail, the diver should be decompressed according to the Surface Decompression Table Using Air disregarding all time spent breathing oxygen.

Example—

Problem—Determine the decompression schedule for a dive to 136 feet for 62 minutes using the Surface Table Using Oxygen.

Solution—The correct decompression schedule for a dive to 136 feet for 62 minutes is the 140/65 schedule. The decompression profile is illustrated in Figure 7-5.

Surface Decompression Table Using Air 7.5.5

The Surface Table Using Air should be used for surface decompression after an air dive when a recompression chamber without an oxygen breathing system is available. Also, if oxygen breathing must be stopped at any time when decompressing on the Surface Table Using Oxygen, the applicable chamber stops listed in the Surface Table Using Air must be carried out in their entirety.

The total ascent times of the Surface Table Using Air exceed those of the Standard Air Decompression Table. The advantages of using this table are strictly those of maintaining the diver in a controlled, closely observed environment during decompression.

When employing the Surface Table Using Air, the diver should ascend from the last water stop at 60 fpm. The time spent on the surface should not exceed 3½ minutes and the rate of descent to the first chamber stop should be 60 fpm. The total elapsed time for these three procedures must not exceed 5 minutes.

SURFACE DECOMPRESSION TABLE USING OXYGEN

Depth (feet)	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) breathing air at water stops (ft) 60	50	40	30	Surface interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompression time (min:sec)
70	52	2:48	0	0	0	0		0		2:48
	90	2:48	0	0	0	0		15		23:48
	120	2:48	0	0	0	0		23		31:48
	150	2:28	0	0	0	0		31		39:48
	180	2:48	0	0	0	0		39		47:48
80	40	3:12	0	0	0	0		0		3:12
	70	3:12	0	0	0	0		14		23:12
	85	3:12	0	0	0	0		20		29:12
	100	3:12	0	0	0	0		26		35:12
	115	3:12	0	0	0	0		31		40:12
	130	3:12	0	0	0	0		37		46:12
	150	3:12	0	0	0	0		44		53:12
90	32	3:36	0	0	0	0		0		3:36
	60	3:36	0	0	0	0		14		23:36
	70	3:36	0	0	0	0		20		29:36
	80	3:36	0	0	0	0		25		34:36
	90	3:36	0	0	0	0		30		39:36
	100	3:36	0	0	0	0		34		43:36
	110	3:36	0	0	0	0		39		48:36
	120	3:36	0	0	0	0		43		52:36
	130	3:36	0	0	0	0		48		57:36
100	26	4:00	0	0	0	0		0		4:00
	50	4:00	0	0	0	0		14		24:00
	60	4:00	0	0	0	0		20		30:00
	70	4:00	0	0	0	0		26		36:00
	80	4:00	0	0	0	0		32		42:00
	90	4:00	0	0	0	0		38		48:00
	100	4:00	0	0	0	0		44		54:00
	110	4:00	0	0	0	0		49		59:00
	120	4:00	0	0	0	3		53		63:00
110	22	4:24	0	0	0	0		0		4:24
	40	4:24	0	0	0	0		12		22:24
	50	4:24	0	0	0	0		19		29:24
	60	4:24	0	0	0	0		26		36:24
	70	4:24	0	0	0	0		33		43:24
	80	3:12	0	0	0	1		40		51:12
	90	3:12	0	0	0	2		46		58:12
	100	3:12	0	0	0	5		51		66:12
	110	3:12	0	0	0	12		54		76:12
120	18	4:48	0	0	0	0		0		4:48
	30	4:48	0	0	0	0		9		19:48
	40	4:48	0	0	0	0		16		26:48
	50	4:48	0	0	0	0		24		34:48
	60	3:36	0	0	0	2		32		44:36
	70	3:36	0	0	0	4		39		53:36
	80	3:36	0	0	0	5		46		61:36
	90	3:12	0	0	3	7		51		72:12
	100	3:12	0	0	6	15		54		86:12

Surface interval: TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES

Surface: 2-MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN

SURFACE DECOMPRESSION TABLE USING OXYGEN

Depth (feet)	Bottom time (min)	Time to first stop or surface (min:sec)	Time (min) breathing air at water stops (ft) 60	50	40	30	Surface interval	Time at 40-foot chamber stop (min) on oxygen	Surface	Total decompressic time (min:sec)
130	15	5:12	0	0	0	0	TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES	0	2-MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	5:12
	30	5:12	0	0	0	0		12		23:12
	40	5:12	0	0	0	0		21		32:12
	50	4:00	0	0	0	3		29		43:00
	60	4:00	0	0	0	5		37		53:00
	70	4:00	0	0	0	7		45		63:00
	80	3:36	0	0	6	7		51		75:36
	90	3:36	0	0	10	12		56		89:36
140	13	5:36	0	0	0	0		0		5:36
	25	5:36	0	0	0	0		11		22:36
	30	5:36	0	0	0	0		15		26:36
	35	5:36	0	0	0	0		20		31:36
	40	4:24	0	0	0	2		24		37:24
	45	4:24	0	0	0	4		29		44:24
	50	4:24	0	0	0	6		33		50:24
	55	4:24	0	0	0	7		38		56:24
	60	4:24	0	0	0	8		43		62:24
	65	4:00	0	0	3	7		48		70:00
	70	3:36	0	2	7	7		51		79:36
150	11	6:00	0	0	0	0		0		6:00
	25	6:00	0	0	0	0		13		25:00
	30	6:00	0	0	0	0		18		30:00
	35	4:48	0	0	0	4		23		38:48
	40	4:24	0	0	3	6		27		48:24
	45	4:24	0	0	5	7		33		57:24
	50	4:00	0	2	5	8		38		66:00
	55	3:36	2	5	9	4		44		77:36
160	9	6:24	0	0	0	0		0		6:24
	20	6:24	0	0	0	0		11		23:24
	25	6:24	0	0	0	0		16		28:24
	30	5:12	0	0	0	2		21		35:12
	35	4:48	0	0	4	6		26		48:48
	40	4:24	0	3	5	8		32		61:24
	45	4:00	3	4	8	6		38		73:00
170	7	6:48	0	0	0	0		0		6:48
	20	6:48	0	0	0	0		13		25:48
	25	6:48	0	0	0	0		19		31:48
	30	5:12	0	0	3	5		23		44:12
	35	4:48	0	4	4	7		29		57:48
	40	4:24	4	4	8	6		36		72:24

SURFACE DECOMPRESSION TABLE USING AIR

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min) 30	20	10	Surface Interval	Chamber stops (air) (min) 20	10	Total ascent time (min:sec)
40	230	0:30			3	TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		7	14:30
	250	:30			3			11	18:30
	270	:30			3			15	22:30
	300	:30			3			19	26:30
50	120	:40			3			5	12:40
	140	:40			3			10	17:40
	160	:40			3			21	28:40
	180	:40			3			29	36:40
	200	:40			3			35	42:40
	220	:40			3			40	47:40
	240	:40			3			47	54:40
60	80	:50			3			7	14:50
	100	:50			3			14	21:50
	120	:50			3			26	33:50
	140	:50			3			39	46:50
	160	:50			3			48	55:50
	180	:50			3			56	63:50
	200	:40		3			3	69	80:10
70	60	1:00			3			8	16:00
	70	1:00			3			14	22:00
	80	1:00			3			18	26:00
	90	1:00			3			23	31:00
	100	1:00			3			33	41:00
	110	:50		3			3	41	52:20
	120	:50		3			4	47	59:20
	130	:50		3			6	52	66:20
	140	:50		3			8	56	72:20
	150	:50		3			9	61	78:20
	160	:50		3			13	72	93:20
	170	:50		3			19	79	106:20
80	50	1:10			3			10	18:10
	60	1:10			3			17	25:10
	70	1:10			3			23	31:10
	80	1:00		3			3	31	42:30
	90	1:00		3			7	39	54:30
	100	1:00		3			11	46	65:30
	110	1:00		3			13	53	74:30
	120	1:00		3			17	56	81:30
	130	1:00		3			19	63	90:30
	140	1:00		26			26	69	126:30
	150	1:00		32			32	77	146:30
90	40	1:20			3			7	15:20
	50	1:20			3			18	26:20
	60	1:20			3			25	33:20
	70	1:10		3			7	30	45:40
	80	1:10		13			13	40	71:40
	90	1:10		18			18	48	89:40
	100	1:10		21			21	54	101:40
	110	1:10		24			24	61	114:40
	120	1:10		32			32	68	137:40
	130	1:00	5	36			36	74	156:40

SURFACE DECOMPRESSION TABLE USING AIR

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min) 50	40	30	20	10	Surface Interval	Chamber stops (air) (min) 20	10	Total ascent time (min:sec)
100	40	1:30					3	TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES		15	23:30
	50	1:20				3			3	24	35:50
	60	1:20				3			9	28	45:50
	70	1:20				3			17	39	64:50
	80	1:20				23			23	48	99:50
	90	1:10			3	23			23	57	111:50
	100	1:10			7	23			23	66	124:50
	110	1:10			10	34			34	72	155:50
	120	1:10			12	41			41	78	177:50
110	30	1:40					3			7	15:40
	40	1:30				3			3	21	33:00
	50	1:30				3			8	26	43:00
	60	1:30				18			18	36	78:00
	70	1:20			1	23			23	48	101:00
	80	1:20			7	23			23	57	116:00
	90	1:20			12	30			30	64	142:00
	100	1:20			15	37			37	72	167:00
120	25	1:50					3			6	14:50
	30	1:50					3			14	22:50
	40	1:40				3			5	25	39:10
	50	1:40				15			15	31	67:10
	60	1:30			2	22			22	45	97:10
	70	1:30			9	23			23	55	116:10
	80	1:30			15	27			27	63	138:10
	90	1:30			19	37			37	74	173:10
	100	1:30			23	45			45	80	189:10
130	25	2:00					3			10	19:00
	30	1:50				3			3	18	30:20
	40	1:50				10			10	25	51:20
	50	1:40			3	21			21	37	88:20
	60	1:40			9	23			23	52	113:20
	70	1:40			16	24			24	61	131:20
	80	1:30		3	19	35			35	72	170:20
	90	1:30		8	19	45			45	80	203:20
140	20	2:10					3			6	15:10
	25	2:00				3			3	14	26:30
	30	2:00				5			5	21	37:30
	40	1:50			2	16			16	26	66:30
	50	1:50			6	24			24	44	104:30
	60	1:50			16	23			23	56	124:30
	70	1:40		4	19	32			32	68	161:30
	80	1:40		10	23	41			41	79	200:30
150	20	2:10				3			3	7	19:40
	25	2:10				4			4	17	31:40
	30	2:10				8			8	24	46:40
	40	2:00			5	19			19	33	82:40
	50	2:00			12	23			23	51	115:40
	60	1:50		3	19	26			26	62	142:40
	70	1:50		11	19	39			39	75	189:40
	80	1:40	1	17	19	50			50	84	227:40

SURFACE DECOMPRESSION TABLE USING AIR

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min) 50	40	30	20	10	Surface Interval	Chamber stops (air) (min) 20	10	Total ascent time (min:sec)
160	20	2:20				3		TOTAL TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP NOT TO EXCEED 5 MINUTES	3	11	23:50
	25	2:20				7			7	20	40:50
	30	2:10			2	11			11	25	55:50
	40	2:10			7	23			23	39	98:50
	50	2:00		2	16	23			23	55	125:50
	60	2:00		9	19	33			33	69	169:50
	70	1:50	1	17	22	44			44	80	214:50
170	15	2:30				3			3	5	18:00
	20	2:30				4			4	15	30:00
	25	2:20			2	7			7	23	46:00
	30	2:20			4	13			13	26	63:00
	40	2:10		1	10	23			23	45	109:00
	50	2:10		5	18	23			23	61	137:00
	60	2:00	2	15	22	37			37	74	194:00
	70	2:00	8	17	19	51			51	86	239:00
180	15	2:40				3			3	6	19:10
	20	2:30			1	5			5	17	35:10
	25	2:30			3	10			10	24	54:10
	30	2:30			6	17			17	27	74:10
	40	2:20		3	14	23			23	50	120:10
	50	2:10	2	9	19	30			30	65	162:10
	60	2:10	5	16	19	44			44	81	216:10
190	15	2:50				4			4	7	22:20
	20	2:40			2	6			6	20	41:20
	25	2:40			5	11			11	25	59:20
	30	2:30		1	8	19			19	32	86:20
	40	2:30		8	14	23			23	55	130:20
	50	2:20	4	13	22	33			33	72	184:20
	60	2:20	10	17	19	50			50	84	237:20

CHAPTER EIGHT

DIVING EMERGENCIES

An emergency, by definition, is an unforeseen combination of circumstances or the resulting state that calls for immediate action. Because of the characteristics of the underwater environment, a situation which might only be annoying on the surface may assume life-or-death proportions for a working diver.

By training and experience, a diver must be able to handle the wide range of actual and potential emergency situations which he may encounter. He must be able to separate the important from the trivial, while at the same time recognizing the dangers which a seemingly minor symptom or event may foreshadow. He must be able to identify and properly react to the warning signals of various physiological disorders, whether affecting himself or other divers. He must have a working knowledge of the most effective methods for handling physical emergencies (such as entrapment or malfunctioning equipment) as well as a basic knowledge of the correct steps to be taken in treating medical emergencies.

And, most importantly, he must be able to work toward solving the emergency while he himself is under the emotional and physical stress which is almost certain to be one component of any emergency situation.

Knowledge and training are vital. Men who are well-trained, well-rested, alert and confident, only rarely cannot cope with an emergency. An operation that is thoroughly planned, with a carefully paced workload and the prior organization of all necessary personnel, equipment and supplies, tends to be a safer operation. Equipment in good repair, properly maintained and not jury-rigged or "adapted" to a non-designed task, is usually safe equipment. And finally, while the environment of the dive cannot be directly controlled, it can be understood and any hazardous elements provided for with special training, equipment or scheduling.

This chapter does not cover every possible situation which may cause problems for a diver, nor will it serve as a text on basic First Aid. Other sections of this manual cover general work procedures, including some which apply in emergency situations, and other publications present sufficient material on general medical procedures that this information need not be repeated here.

This chapter specifically details those emergencies which—

—may be a matter of life or death

—are unique to diving

—may seriously interfere with the success of an operation

MEDICAL EMERGENCIES—IMMEDIATE ACTION 8.1

Diving personnel who require emergency medical treatment fall into one of two classes: those who require recompression, and those who do not. All members of the diving team should be able to make this differentiation and should have sufficient knowledge and training to proceed with appropriate treatment or corrective action. It may well be that no treatment would be the most appropriate course of action, especially for non-medical personnel, and the first rule of first aid is to do nothing that will do harm to the patient. However, there are four medical problems which must be solved immediately and cannot wait for the arrival of medical personnel.

In order of priority, the immediate actions which must be taken are—

—assure clear airway

—restore breathing

—assure heart function

—stop massive bleeding

Following these four steps, a more thorough diagnosis of the problem can be made and the assistance of more-qualified personnel obtained. From that point, the person helping a severely injured man will best serve his patient by protecting him from further harm, and by striving to maintain breathing, heart beat and blood circulation in a stable condition. Other treatment, such as placement in a recompression chamber, may be concurrent with these procedures. This will be covered in a later section.

Resuscitation 8.1.1 Resuscitation is a general term which covers all the measures taken to restore vital signs, particularly breathing and heart beat.

These measures include pulmonary resuscitation to restore breathing and cardiac resuscitation to re-establish normal heart action.

PULMONARY RESUSCITATION 8.1.1.1. A cessation of breathing, leading to asphyxia, can very quickly result in cell damage and death. The problem may be the result of a number of factors which must be considered in connection with any attempts to restore breathing. These are—

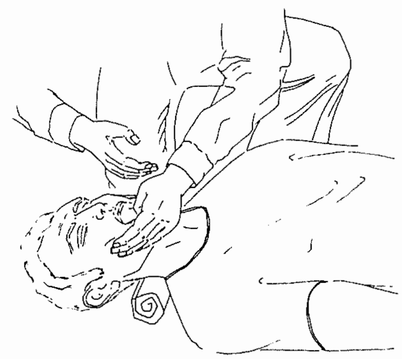
1. Mechanical blockage of the air passages by water, vomitus, blood clots, or foreign bodies.
2. Blockage of the air passages by abnormal swelling and increased secretions of mucous membranes which may be caused by allergic reactions or severe inflamation.
3. Dysfunction of the respiratory muscle action or disruption of the chest breathing action which may be caused by chest trauma.
4. Paralysis of the respiratory system as a result of nerve injury caused by—
   a) damage to the spine or brain
   b) electric shock

The first action is to assure a clear airway before starting resuscitation. Vomitus or objects lodged in the throat, for example, can often be cleared with a finger (taking care not to push the material more firmly into place).

Once a clear airway has been established, manual pulmonary resuscitation may be started. Manual resuscitation should be continued until a mechanical resuscitator is made available.

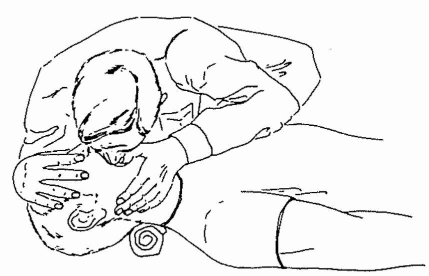
Mouth-to-Mouth Resuscitation— Of the several methods of manual pulmonary resuscitation which have been developed—mouth-to-mouth, back pressure-armlift, chest pressure-armlift, back pressure-hiplift—the only effective, and the method of choice for initial resuscitation until a bag resuscitator is available, is the mouth-to-mouth technique. Although the other techniques may prove of value in certain situations, such as excessive vomiting or facial injuries, the mouth-to-mouth is the only successful technique in the majority of cases. Detailed instructions for performing mouth-to-mouth resuscitation will be found in Figure No. 8-1.

The use of an S-shaped plastic airway is often advantageous in conducting mouth-to-mouth resuscitation, and one should be part of every first aid kit.



Lift Neck
Lift the neck and extend the head to open air passage.

Extend Head
Draw down the victim's lower lip. Pull chin upward until head is tilted back fully. Pinch off the nostrils with your other hand, this prevents air leakage when inflating the lungs.



Inflate Lungs
Place your mouth over the mouth of an adult or large child. For a small child place your mouth over both the nose and mouth. Make a tight seal and blow into the air passages until the chest rises. Infants and small children only need small puffs of air. Remove your mouth and let the patient breathe out through his nose or mouth. Continue this at the rate of 10-12 times per minute for an adult, and at least 20 times a minute for a child. For Mouth to Nose Resuscitation, inflate the lungs through the nose, keeping the mouth closed.

Figure 8-1 Mouth-to-Mouth resuscitation.

The victim is placed on his back in a comfortable position and a "pillow" (in this case a wet suit top) is positioned under his neck. His wet suit top is opened.

His chin is then lifted, and his mouth cleared of any foreign matter.

The resuscitator mask is then placed and firmly held over his nose and mouth, and the bag is squeezed and released in a rhythmic manner to simulate normal respiration. The operator should check the victim's chest movements to insure proper operation of the resuscitator.

The mechanical bag resuscitator may also be used with a pure oxygen supply. Operational procedures are identical except that oxygen rather than air is forced into the victim's lungs.

Figure 8-2 Mechanical Bag Resuscitator

Use of the airway offers not only an aesthetic advantage over direct mouth contact, but also helps to maintain a clear air passage. However, the airway may cause the patient to gag and vomit if left in place when he starts to respond to resuscitation efforts.

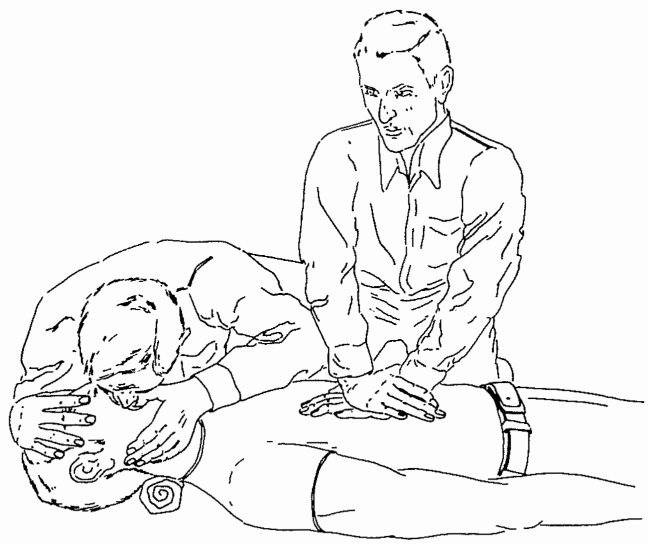
Mouth-to-mouth resuscitation must be continued without interruption. If the principal attendant becomes fatigued, his relief must take over without breaking the rhythm. If the patient shows any signs of an effort to regain natural breathing, the timing of the cycle should be adjusted to match his effort. If the patient starts to breathe for himself, he should be watched closely and resuscitation resumed if his effort falters or seems to become too feeble.

Once mouth-to-mouth resuscitation has begun, treatment of other injuries can be administered. The patient should be kept lying down. He should be made as comfortable as possible; wet clothing should be removed, and he should be kept warm. No attempt should be made to give him any food, drink or medicine by mouth until he is fully conscious. And, as promptly as possible, he must be examined by a medical officer—even if there do not seem to be any residual ill-effects from the emergency.

Mechanical Resuscitation—A bag resuscitator, a simple, hand-powered device, can be substituted for mouth-to-mouth resuscitation when it is immediately available (Figure 8-2). It allows the use of oxygen to assist respiration and is readily employed in recompression chambers. All diving units should be equipped with an AMBU-type resuscitator, and all members of the diving team should be thoroughly familiar with the proper operation of the apparatus.

CARDIAC RESUSCITATION 8.1.1.2 Cardiac arrest may result from electric shock or asphyxia, or it can be caused by a combination of factors such as hypoxia, shock or embolism. There are a number of other causes; but, in the immediate emergency situation, the cause is not as important as the effort to restore—or mechanically reproduce—the heart beat. Arrest of heart action can be recognized by the absence of pulse in the major vessels. If the heart has been interrupted more than four minutes, irreversible damage to the brain and other vital organs will usually result.

Closed-chest cardiac massage is a method for artificially continuing the flow of blood to the central nervous system and vital organs. Hopefully, the closed-chest message will result in a spontaneous resumption of the heart beat. If it does not, massage is continued while the patient is being moved to an area of complete medical assistance. Cardiac massage shall be continued until directions to stop are given by a medical officer, or until the victim's pulse remains absent for more than 15 minutes.



Check for pulse at either side of the windpipe on the neck. If none is present, lift neck and extend head to open air passage.

Go into a kneeling position on either side of the patient. Then place the heel of one hand on the lower third of the breastbone with the fingers pointing toward the patient's armpit. Now place the other hand directly on top of the first as shown by the illustration.

Press downward, using your body weight, compressing the chest approximately 1½ inches. (Always use less pressure with children or the aged.) Release pressure immediately. Compress the chest and release once every second, eight consecutive times. After eight compressions, ventilate the lungs ONCE using mouth-to-mouth technique.

This cycle should be maintained by continuously alternating mouth-to-mouth resuscitation with the heart massage. Observe for return of spontaneous cardiac action every 3 minutes.

Figure 8-3 Heart-lung resuscitation; call doctor at once

In closed-chest cardiac massage, the operator applies pressure on the victim's breastbone, which squeezes his heart and serves to simulate the normal pumping action. At the same time, the victim's lungs must be ventilated using mouth-to-mouth resuscitation, or preferably, 100% oxygen administered with a bag resuscitator. Heart-lung resuscitation will help to offset the asphyxia and hypoxia which are a natural result of cardiac arrest; without the circulation of blood, the cells of the brain, and the rest of the body will die due to lack of oxygen. A detailed procedure for performing heart-lung resuscitation is described in Figure No. 8-3.

Control of Massive Bleeding 8.1.2 Massive bleeding must be immediately controlled. If the victim also requires resuscitation, the two problems must be handled simultaneously. Bleeding may involve arteries, and both the urgency and method of treatment may be determined in part by the nature of the source.

Arterial bleeding can be identified as follows:

- bright red blood, gushing forth in jets or spurts which are synchronized with the pulse.

Internal bleeding—the signs of external bleeding are obvious, but the first aid team must be alert for the possibility of unseen, internal hemorrhage. Victims subjected to crushing injuries, heavy blows or deep puncture wounds should be carefully observed for signs of internal bleeding. Signs usually present include:

- moist, clammy, pale skin
- feeble pulse with very rapid pulse rate
- lowered blood pressure
- faintness or actual fainting
- blood in stool, urine or vomitus, or from the mouth

Internal bleeding can only be controlled by trained medical personnel and often only under hospital conditions. Efforts in the field are generally limited to replacing lost volume through infusion of saline, Ringer's lactate or other fluids.

EXTERNAL ARTERIAL HEMORRHAGE 8.1.2.1 There is only one effective measure which can be used to control external arterial hemorrhage—direct pressure on the wound. The pressure is best applied with sterile compresses, placed directly and firmly over the wound. In a crisis, almost any material can be used.

Two alternate methods of controlling bleeding, often suggested in medical texts, are by applying pressure to the various pressure points in the body and by applying a tourniquet. In almost every instance, these methods have proven to be significantly less effective than local pressure. The location of pressure points is easily forgotten in emergency circumstances. Additionally, even when the pressure point technique is properly applied, collateral circulation will usually allow the hemorrhage to persist.

A tourniquet is a constricting band which, when tightened about the appendage above the wound, practically stops the flow of blood to the wound. This method of controlling bleeding often results in the later need for amputation of the damaged appendage, and for that reason a tourniquet should only be applied when amputation is judged an inevitable consequence of the wound.

EXTERNAL VENOUS HEMORRHAGE 8.1.2.2 Venous hemorrhage is not as dramatic as severe arterial bleeding, but if left unchecked, can be equally serious. Venous bleeding can almost always be adequately treated by direct pressure on the wound.

MEDICAL EMERGENCIES— NON-RECOMPRESSION TREATMENT 8.2

Any emergency in a diving situation could result in a requirement for medical treatment. Many of these emergencies are analogous to those encountered in any environment, and normal first aid measures are employed. In some circumstances, such as traumatic injuries occuring under water, the need for decompression may complicate procedures. Thus the need for adequate dive decompression may affect wound management techniques. In serious situations a judgement may be required to bypass normal decompression and risk decompression sickness in favor of rendering immediate aid to the diver.

Aside from the complications introduced by recompression considerations, medical aid follows the procedures in the Handbook of the Hospital Corps NAVMED P-5004. This section of the Diving Manual concerns disorders which are unique to diving, require special procedures, and are not treated by recompression. For convenience these problems can be divided into two areas—

1. Respiratory emergencies, as directly related to the quantity and quality of the breathing supply.
2. In-water emergencies with direct medical involvement.

The most serious conditions which can apply to any of these categories have already been covered—

cessation of breathing
cardiac arrest
massive hemorrhage.

A potentially serious symptom which may be common to these categories is loss of consciousness which may be both a warning of a severe problem and a complicating factor in any diagnosis.

Loss of consciousness can be the result of near-drowning, inadequate oxygen, an oxygen convulsion or an excess of carbon dioxide in the blood. But, in diving, loss of consciousness must be considered to be a symptom of the most dangerous problems—gas embolism and decompression sickness. Recompression should be given in almost every case of unconsciousness simply because it is seldom possible to be certain that it is not essential. If satisfied that recompression is not called for in a given case, then treatment can progress along other lines, as outlined in the following sections.

Respiratory Emergencies 8.2.1 All human life is directly dependent upon the quantity and quality of it's breathing mixture. Any deviations from established standards can result in a number of respiratory problems. Because of the particular nature of the underwater environment, any such problem—which on the surface might easily be handled as a transient annoyance—must be handled as an emergency.

Not all respiratory problems must necessarily result in the termination of the dive—if they are identified and corrected soon enough. With most, however, the need to ensure the safety of the diver will outweigh an operational requirement to complete a planned dive, and the diver should be brought to the surface for treatment and thorough examination by medical personnel. Beware of the diver who reports from the bottom "I think I'm OK now" and wants to continue his assignment.

Every diver and every other member of the diving team must know the warning signs and symptoms of each of these problems:

Oxygen deficiency (hypoxia)
Carbon dioxide poisoning
Carbon monoxide poisoning
Asphyxia
Strangulation
Chemical irritants
Nitrogen narcosis
Oxygen poisoning (toxicity)

SYMPTOMS/TREATMENT OF RESPIRATORY DISORDERS 8.2.1.1

A. Oxygen Deficiency—Although the specific cause varies as discussed in Chapter Three, the following disorders all result in the same condition—a shortage of oxygen reaching the cells for normal metabolism. In summary, these disorders are—

—**Hypoxia**, caused by loss or inadequacy of the air supply.

—**Carbon dioxide poisoning**, resulting from inadequate ventilation of apparatus, overexertion, controlled or "skip" breathing, excessive dead space in equipment.

—**Carbon monoxide poisoning**, caused by induction of exhaust fumes into the air supply compressor.

—**Asphyxia**, simultaneous oxygen deficiency and carbon dioxide excess usually caused by loss or inadequacy of the air supply.

—**Strangulation**, obstruction of the airway by a foreign object, laryngal spasm or abnormal swelling.

—**Chemical irritants**, presence of irritating chemicals contaminating the air supply resulting in pulmonary edema.

Symptoms of Oxygen Deficiency—The following signs and symptoms may be noted in situations involving oxygen deficiency—

Labored breathing	Lack of muscular coordination
Mental confusion	
Bad taste	Headache
Nausea	Chest discomfort
Unconsciousness	Weakness

Treatment of Oxygen Deficiency—The following procedures should be followed if oxygen deficiency is suspected—

1. Abort the dive.
2. Switch to an alternate air supply.
3. Send down the standby diver to assist.
4. Thoroughly ventilate the apparatus.
5. Administer 100% oxygen.

B. Nitrogen Narcosis—The narcotic effect of high partial pressures of nitrogen can produce euphoria, disorientation, lapses of rationality or judgement, and other behavior similar to that of alcoholic intoxication. Nitrogen narcosis is normally encountered below 100 ft. and may result from exceeding established depth limits.

Treatment of Nitrogen Narcosis—Reduction of the nitrogen partial pressure is the standard procedure for treatment. Specifically—

1. Diver should ascend to a shallower depth.
2. If mental acuity is not restored, abort the dive.

C. Oxygen Toxicity—As discussed in Chapter Three, oxygen toxicity (poisoning) can result from the inspiration of oxygen at partial pressures greater than 0.6 ata. Established depth and bottom time limits normally preclude the possibility of the development of in-water oxygen toxicity in air diving. Oxygen toxicity in air diving may be encountered while administering 100% oxygen during surface decompression procedures.

Symptoms of Oxygen Toxicity—The following signs and symptoms may be noted in situations involving oxygen toxicity—

Muscle twitching	Abnormal vision (particularly "tunnel vision")
Muscle twitching	Hearing abnormalities
Nausea	Convulsions
Dizziness	

Behavioral abnormalities (irritability, anxiety, confusion, unusual fatigue)

Incoordination	Convulsions

Treatment of Oxygen Toxicity—Procedures for treating oxygen toxicity involve immediate reduction in oxygen partial pressure and protection of the diver from physical injury if he begins to convulse. Specifically—

1. Stop mask breathing and breathe chamber atmosphere.
2. If symptoms persist, switch to an air decompression schedule.
3. If the diver is having convulsions, protect him from physical harm and protect his tongue with a padded depressor.

In-Water Emergencies With Direct Medical Involvement 8.2.2 Emergencies discussed in this section are those which arise out of the nature of the diving environment—drowning, pressure imbalance, and problems of low temperatures and heat loss leading to emergency conditions.

DROWNING 8.2.2.1 A swimmer can fall victim to drowning because of over-exertion, panic, inability to cope with rough water, exhaustion, or the effects of cold water or heat loss (see page 8-8). These same factors can affect a diver but, if he is properly equipped, trained and monitored by a buddy or a surface tender, drowning should be a remote possibility. Unfortunately, divers do drown—even when equipped, trained and tended.

Drowning with deep-sea gear 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 the spit cock open, his chin pressing on the chin button, or his suit torn. Normally, as long as he is in an upright position and has a supply of air he can keep the water out of his helmet no matter what the condition of his suit.

Divers wearing lightweight or SCUBA gear can drown if they lose or ditch their mask or mouthpiece. This could be the direct result of the failure of the air supply, or of panic in a hazardous situation. The SCUBA diver, because he is so directly exposed to the environment, can be directly affected by the same conditions which may cause a swimmer to drown.

The prevention of drowning is best insured by the establishment of, and thorough training in, safe diving practices coupled with the careful selection of diving personnel. A physically-fit, confident diver, equipped with proper gear, should not easily fall victim to drowning. At the same time, however, overconfidence—in both self and equipment—can give a feeling of security that might lead a diver to take dangerous risks.

The treatment of near-drowning falls into two phases: one, restore breathing and heartbeat, and, two, call for assistance from qualified medical personnel. Regardless of the mildness or severity of a near-drowning case, all victims should be hospitalized as quickly as possible. The occurence of pulmonary edema (accumulation of fluids in the lungs), pneumonia, and other complications may be delayed for many hours after the incident and proper medical observation is essential. Subsequent to resuscitation while awaiting transportation to medical facilities, the patient should be kept warm and rested.

SQUEEZE 8.2.2.2 Basically, squeeze or barotrauma is caused by a lack of pressure equalization between parts of the body or between the body and diving equipment. It normally occurs during descent. A full discussion of the topic will be found in Section, 3.6. Squeeze may be categorized by location and/or cause as follows—

—Middle-ear squeeze, caused by a blocked eustachian tube.

—External-ear squeeze, caused by a hood or other piece of equipment covering the external ear passage.

—Lung (thoracic) squeeze, which may happen when the air in the lungs is compressed to less than residual volume. This could happen in an extremely deep breathhold (free) dive.

—Body squeeze (with deep-sea diving dress), caused by a failure of the air supply to balance water pressure; can be precipitated by a fall into water of greater depth, or by the malfunction or maladjustment of supply and exhaust valves, or by the absence or failure of the safety air non-return valve.

—Face-mask squeeze, caused by a failure to equalize air in the mask by nasal exhalation, or, with full-face mask, by malfunction of the air supply or the valving.

—Suit squeeze, normally occurs in dry-type suits in which a pocket of air becomes trapped under a fold or fitting and pinches the skin in the fold area.

Treatment of Squeeze—Squeeze may be relieved by the following procedures—

1. Stop descent.
2. If efforts to equalize pressure fail, ascend to shallower depth.
3. If further efforts to equalize pressure fail, abort the dive.

4. If an ear drum rupture is suspected, send down the standby diver to assist.
5. Report any physical injury to the medical officer for appropriate treatment.

THERMAL CONSIDERATIONS 8.2.2.3 The problems caused by diving in cold water, or by body heat loss in water below a temperature of about 72°F, are more serious than often realized and affect not only diver efficiency but threaten his life as well.

Sudden immersion in very cold water results in the diver being unable to hold his breath which causes him to lose bouyancy. He hyperventilates uncontrollably and loses his ability to coordinate swimming maneuvers. Prolonged immersion will result in profound heat loss (hypothermia) and rapid deterioration of mental and physical performance.

In water below 41°F (5.5°C), an unclothed man of average body build will probably become helpless from hypothermia in less than 30 minutes. He can withstand immersion at 59°F (15.5°C) for up to approximately 2 hours. If wearing heavy, conventional clothing these times can be more than doubled, and for divers, wearing adequate diving dress and insulating underwear, immersion time can be significantly increased. There is, of course, a wide range of individual tolerance to immersion in cold water which occur primarily as a result of the insulating effects of body fat. Overweight personnel normally have significantly greater cold water endurance than thin people.

There are two rules which must be observed by a man who is in the water with inadequate thermal protection and finds himself becoming incapacitated by the cold—

1. If the water temperature is below 77°F (35°C) do not move any more than is absolutely necessary. At temperatures above 77°F, exercise will help increase the production of heat and help forestall hypothermia; at temperatures below 77°F, exercise will increase the loss of body heat.
2. If supported by a life preserver or a floating object, and if rescue or pick-up seems reasonably certain, do not attempt to swim for shore or a boat. Very good swimmers, in very cold water, have failed to cover distances as short as 200 yards.

Hypothermia is an emergency condition and must be quickly treated. Merely getting the victim out of the water is not enough to save his life, as the loss of heat from the inner organs will continue for some time as long as the skin temperature remains low. Putting a blanket around the victim will be of little help except in very mild cases—his body will not be generating enough heat to provide any warmth under the blanket.

Active warming must be initiated at once. This can include use of heaters, fires, hot showers or hot baths. Giving the victim hot liquids or alcoholic beverages will probably have a positive psychological effect but will usually not have much physiological benefit.

In extreme cases, where the victim is apparently dead, a hot bath combined with mouth-to-mouth resuscitation and external cardiac massage may prove successful. The bath should be as hot as 110°F (44°C) and the victim's trunk should be fully immersed, with his arms and legs out of the water. The bath must be discontinued when the heart beat and respiration are regular and increasing in frequency, accompanied by a general improvement of condition, or if his deep body temperature reaches 91°F (32.8°C) and is rising steadily. From this point, he should be wrapped in blankets and allowed to rewarm spontaneously.

Complications which may arise, such as sudden deterioration of condition or loss of blood pressure, require the immediate attention of medical personnel.

If any personnel should suffer from frozen extremities, resulting from exposure or immersion, they may be given initial treatment as follows—

1. If still actually frozen, thaw the affected extremity quickly by immersion in water at 104°F (40°C).
2. If already thawed after having been frozen, keep the limb dry, give the patient drugs to relieve pain and otherwise leave alone.
3. In the case of a non-freezing injury—where the limbs may have been kept at just above freezing temperature, in or out of the water, for several hours, give the victim a hot immersion bath (104 to 110°F, 44°C) but keep the limbs out of the water, keep them elevated and administer pain-relieving drugs.

In all such cases, the victim should be seen by a doctor as soon as possible.

Another thermal condition which may require emergency treatment is heat exhaustion—always a possibility when the diver is working in waters above 95°F (35°C). Prevention is the result of good planning and careful avoidance of over-work. Treatment consists of placing the casualty in a reclining position in a cool environment and giving cool water, containing 0.1 percent sodium chloride, by mouth.

POLLUTION POISONING 8.2.2.4 Divers who will be operating in contaminated water, or where contamination (as from a leaking barge) is likely, should be provided with appropriate protective gear and required prophylaxis, e.g., ear washing solution, should be available at the diving station. These procedures are properly part of the planning phase of the operation; medical personnel should be consulted for the correct treatment for the type of exposure that may be encountered by the divers.

GAS EXPANSION 8.2.2.5 Occasionally, a diver may experience various types of internal gas expansion. For example, in rare instances, a middle ear or sinus that has equalized on descent may block on ascent, trapping a pocket of gas. Slowing the rate of ascent will usually permit the gas to escape without additional complications.

A more common condition results from the generation of gas in the intestines during a dive, or from the swallowing of air which becomes trapped in the stomach. These pockets of gas will usually work their way out of the system through the natural vents. If not, and if the pain begins to pass the stage of mild discomfort, ascent should be halted and the diver should descend slightly until the pain is relieved. Then, he should attempt to belch or release the gas anally—with a caution, however; overzealous attempts to belch may result in swallowing more air.

Most intestinal gas expansion can be avoided by a few simple precautions—do not dive with an upset stomach or bowel, avoid eating foods which are likely to produce intestinal gas, and avoid swallowing air during a dive.

MEDICAL EMERGENCIES REQUIRING RECOMPRESSION 8.3

There are two basic classes of medical emergency which require treatment by recompression—gas embolism (and several related conditions) and decompression sickness. Gas embolism is the most dangerous, and must be treated as an extreme emergency. It is an accident which can occur during a brief, shallow dive—even a dive made in a swimming pool with breathing equipment. It develops rapidly, and must be treated quickly. Decompression sickness can be just as serious, but may develop quite gradually up to 24 hours after the completion of a seemingly routine and uneventful dive. Decompression sickness is not unique to diving—it can affect aviators or men working in pressure chambers—but can only occur when "decompression" (a reduction in the pressure surrounding the body) has taken place.

Gas Embolism and Related Conditions 8.3.1

Gas embolism is caused by the expansion of gas which has been taken into the lungs while breathing under pressure and held in the lungs during an ascent. The gas might have been retained in the lungs by choice (voluntary breathholding) or by accident (as when the air passages become blocked). The gas could have become trapped in an obstructed portion of the lung which was the result of damage from some previous disease or accident. Or the diver, reacting with panic to a difficult situation, may hold his breath without realizing that he is doing so.

However the gas may have become trapped in the lungs, it will expand as the diver rises. If there is enough gas, and if it expands sufficiently, the pressure will tend to force gas through the alveolar walls and into the bloodstream and surrounding tissues.

The gas thus forced into the blood may be carried by arteries throughout the body. These gas bubbles may lodge in the arteries, the spinal cord or the brain, cutting off blood circulation. Gas which has been forced into the lung tissues may also flow under the skin and collect around the heart or in the chest causing collapse of a lung.

The term gas embolism, as used in diving, refers to gas which has been forced into the bloodstream. The related conditions which result when the gas is forced into the tissues are—

- mediastinal emphysema, gas trapped in the tissues of the chest around the heart, great vessels and lungs.

—subcutaneous emphysema, gas trapped under the skin (often in the area of the neck, having moved up from the point of rupture or "leaking" in the lungs).
—pneumothorax, where the gas is caught between the lungs and the chest wall.

The potential hazard of gas embolism may be prevented or substantially reduced by careful attention to the following—

A. Medical selection of diving personnel, with particular attention to elimination of men who show evidence of lung disease or who have a past history of respiratory disorders.

B. Evaluation of physical condition immediately before a dive—any impairment of respiration, as from a cold, bronchitis, etc., must be considered to be potentially disqualifying.

C. Every diver must be given proper, intensive training in diving physics and physiology as well as in the correct use of various diving equipment. Particular attention must be given to the training of SCUBA divers because of the comparatively high incidence of embolism accidents experienced in SCUBA operations.

D. A diver must never hold his breath during ascent from a dive in which breathing apparatus has been used.

E. When making an emergency ascent, the diver must exhale continuously. The rate of exhalation must match the rate of ascent. For a free ascent, where the diver uses his natural buoyancy to carry him toward the surface, the rate of exhalation must be great enough to prevent embolism, but not so great that the buoyancy factors are cancelled. With a buoyant ascent, where the diver is assisted by an external source of buoyancy such as a life preserver the rate of ascent may far exceed that of a free ascent. The exhalation must actually begin before the ascent, and must be rapid and continuous. It is difficult for an untrained diver to properly execute an emergency ascent. It is also often dangerous to train a diver in proper technique. No ascent training may be conducted unless fully qualified instructors are involved, and a recompression chamber is available in the immediate vicinity.

F. Other factors in the prevention of gas embolism include good planning, and adherence to the established dive plan. Trying to stretch a dive to finish a task can too easily lead to the exhaustion of the air supply and the need for an emergency ascent. Further, the diver must know and follow good diving practices, must keep himself in good physical condition, and must not hesitate to report any symptoms whatsoever, no matter how trivial they might seem, to the Diving Supervisor.

A case of gas embolism must be diagnosed quickly and correctly. The supply of blood to the brain or spinal cord is almost always involved, and, unless promptly and properly treated (by recompression), gas embolism is likely to result in death or permanent brain damage. By the same token, since the brain is so rapidly affected, definite symptoms of gas embolism are likely to show up within a minute or two after surfacing. Any central nervous system (CNS) symptom, other than unconsciousness, which develops much later should not be regarded as the result of gas embolism. This does not rule out, however, the possibility of other medical conditions without CNS symptoms which are related to gas embolism.

As a basic rule, any diver who may have obtained a breath from any source at depth—whether from diving apparatus or from a diving bell—and who is unconscious or soon loses consciousness upon reaching the surface, must be assumed to be suffering from a gas embolism and recompression treatment must be started immediately. If the diver regains consciousness before recompression has started, and shows no signs of brain injury, gas embolism is probably not involved.

Other factors to consider in diagnosing gas embolism are—

—the onset is usually sudden and dramatic, often occurring within seconds after arrival on the surface, or even long before reaching the surface. The signs and symptoms may include dizziness, paralysis or weakness in the extremities, blurring of vision or convulsions. The diver may have noticed a sensation similar to that of a blow to the chest during the ascent which could signify the rupture of a lung.

The victim may become unconscious without the warning of any of these symptoms, and may even stop breathing.

- some of these symptoms may also be experienced by a diver suffering from decompression sickness. If the dive has been to a depth of less than 33 feet, decompression sickness is unlikely and embolism must be assumed. If the only symptoms are pain, gas embolism is unlikely and decompression sickness or one of the gas embolism-related conditions (which are not usually acute emergencies) should be assumed.
- some symptoms may be masked by environmental factors or by other, less significant, symptoms. A diver who is chilled may not be concerned with numbness in an arm which may actually be the sign of nervous system involvement. Pain from any source may divert attention from other symptoms. The natural anxiety that would accompany a "close call" such as the failure of the diver's air supply might mask an anxiety or state of confusion which is being caused by a gas embolism affecting the brain. A diver who is coughing up blood or bloody froth may be showing signs of ruptured lung tissue —or he may merely have bitten his tongue or have experienced a case of sinus squeeze.

Realistically, ambiguities of this sort will usually be quickly resolved by the appearance of more severe symptoms, however, once the diver is in the recompression chamber, it may be difficult to evaluate symptoms which may be eliminated by the pressurization. The treatment for gas embolism is longer and more detailed than that accorded to other problems requiring recompression because the danger from brain damage is so much greater. ANY DOUBT AS TO CORRECT DIAGNOSIS MUST BE RESOLVED IN FAVOR OF THE DIVER—ASSUME GAS EMBOLISM.

The symptoms of mediastinal emphysema may include pain under the breastbone, shortness of breath and faintness. These latter two would be the result of the trapped gas pressing against the lungs, heart and large blood vessels, thereby interfering with the breathing and/or blood circulation. This might also be evidenced by blueness (cyanosis) of the skin, lips or fingernails.

Subcutaneous emphysema may not be noticed by the victim except in extreme cases, although he might experience a feeling of fullness around the neck and may have difficulty in swallowing. The sound of his voice may change, and an observer may also note a marked swelling or inflation of the neck. Movement of the skin near the collar bone may produce a crackling or crunching sound (crepitation).

Pneumothorax is usually accompanied by a sharp pain in the chest which is aggravated by deep breathing. To minimize this pain, the victim will be breathing in a shallow, rapid manner. He may show signs of hypoxia and may exhibit a tendency to bend the chest toward the side involved. If a lung has in fact been collapsed by the trapped gas, it may be detected by listening to both sides of the chest. A collapsed lung will not produce audible sounds of breathing, depending upon the degree of collapse.

Decompression Sickness 8.3.2 Decompression sickness results from the formation of bubbles in the blood or body tissues and is caused by inadequate decompression following a dive or other exposure to high pressure. Inadequate decompression may occur even when normal precautions are followed. Abnormal conditions in the diver or in his surroundings may cause him to absorb an excessive amount of inert gas or may inhibit the natural elimination of the dissolved gas during normal controlled decompression.

Decompression sickness is best prevented by observing these rules—

- Do not assign diving duties to personnel with physical disabilities, whether from birth, injury or disease, which can result in poor blood circulation.
- Ensure, through direct observation and evaluation, that each man assigned to make a dive is in good physical condition at the time of the dive. Alcoholic intoxication or hangover, excessive fatigue or a general run-down condition are sufficient reasons to restrict a man from diving. If the Diving Supervisor has any doubts, he should consult with a diving medical officer and/or the Diving Officer.
- Prepare a thorough dive plan, measure the depth accurately and carefully compute the time for the

dive and decompression. Then, follow the plan. Make no unplanned dives requiring decompression; avoid decompression dives using SCUBA whenever possible.

—Do not deviate from appropriate decompression tables, unless there is some doubt as to the depth or time of the dive. If so, select a table for a dive of greater depth or longer duration.

—Ensure strict observance, by divers and topside personnel alike, of standard work procedures and safety rules, and ensure, through training schedules and emergency drills, that all personnel will be able to take appropriate action in an emergency.

—A diver must immediately report any post-dive symptoms, even such seemingly minor things as a slight itch or a tingling sensation.

DIAGNOSIS OF DECOMPRESSION SICKNESS

8.3.2.1 Decompression sickness usually causes symptoms within a short period of time following the dive or other pressure exposure. If the controlled decompression during ascent has been shortened or by-passed, the diver could be suffering from decompression sickness before he reaches the surface. In a large sampling of cases, the timing after surfacing for the onset of symptoms was as follows—

—50% occurred within 30 minutes
—85% occurred within 1 hour
—95% occurred within 3 hours
—1% delayed more than 6 hours

Symptoms which occur 24 hours or more following a dive are probably not caused by decompression sickness.

Other factors for evaluating symptoms include the depth and duration of the dive, the decompression tables used, and the probability of other conditions such as gas embolism. The best-qualified person available should make the diagnosis, and the evaluation should not be delayed pending the arrival of a better-qualified person.

A wide range of symptoms may accompany the initial stages of an attack (or "hit") of decompression sickness. The diver may also exhibit certain signs which a trained observer will identify with decompression sickness. Some of the symptoms or signs will be so pronounced that there will be little doubt as to the cause. Others may be subtle, and even some of the more important could be overlooked in a cursory examination of the patient.

Various symptoms of decompression sickness have been found to occur with the following frequency—

Local pain	89%
—Leg	30%
—Arm	70%
Dizziness (the staggers)	5.3%
Paralysis	2.3%
Shortness of breath (the chokes)	1.6%
Extreme fatigue and pain	1.3%
Collapse with unconsciousness	.5%

Decompression Sickness—Pain Only—As will be noted above, the most common symptom is pain in an arm or a leg. These may occur together, of course, or pain may appear in some other part of the body. The pain is usually slight when first noticed, but may grow progressively worse until unbearable. It may seem to come from deep in a bone and will often become centered in a joint. It is sometimes easy to misinterpret pain as a symptom, assuming it to be the result of a muscle sprain or bruise.

If there is any doubt as to the origin of the pain, assume that the diver is suffering from decompression sickness and treat him accordingly.

Abdominal pain (which can easily be confused with a "gas pain") should be regarded as a serious symptom, as it may signal involvement of the spinal cord. With this, or with any other possible nervous system involvement, immediate recompression must be instituted.

Among the more usual symptoms and signs of decompression sickness, the diver might notice a prickling, tingling, itching or burning of the skin, any of which could start in a small area, then spread, and then once again become localized. A sensation of this sort is often the first noticed symptom. An observer should also watch for any skin rash or mottling indicative of skin bends.

Pain may mask other, frequently more significant, symptoms. However, pain should not be treated with drugs in an effort to make the patient more comfortable, because it may well be the only means for localizing the problem and monitoring the progress of any treatment.

Many of the symptoms of decompression sickness are the same as those for gas embolism, and, since the treatment for gas embolism will at the same time be appropriate treatment for decompression sickness, any such confusion of symptoms will not be too important.

Decompression Sickness—CNS—Central nervous system (CNS) involvement is a serious problem requiring immediate treatment, even before a full examination and diagnosis can be performed. If there are any signs that the nervous system is affected, the diver should be recompressed immediately. The examination may be completed in the chamber at treatment pressure. Since CNS treatment is for the most severe possibility, any symptoms which may go unnoticed will probably not be significant.

The symptoms of nervous system involvement include weakness or paralysis of muscles, vertigo, dizziness, ringing in the ears, hearing loss and disturbance of vision. Many of these are easily overlooked, or passed off by the victim as being of no consequence. For this reason, they must be particularly watched for during the immediate post-dive activities of the diver. He may just think he has been working too hard. He may also experience shortness of breath, coughing, or wheezing, or may notice pain when taking a deep breath. In rare instances (about one case in 200), the victim may suddenly lose consciousness and collapse. Again, a symptom of this sort is more usually linked with gas embolism, and treatment should proceed accordingly.

Figure No. 8-4 contains a guide for non-medical personnel to use in forming a diagnosis of decompression sickness. However, one point must always be kept in mind. IF THERE IS ANY DOUBT, RECOMPRESS AND TREAT.

RECOMPRESSION TREATMENT 8.4

When the diver has received inadequate decompression or falls victim to gas embolism, the first treatment procedure is to return the diver to a pressurized environment where the expanded gases will be recompressed to a manageable volume. This will relieve any local pressure caused by the bubbles, will restore normal blood flow and will frequently relieve the patient of many, if not all, of the subjective symptoms. After recompression treatment is underway, additional treatment may be administered.

Certain facets of recompression treatment have been previously mentioned, but they are so important that they cannot be overstressed—

1. Treat promptly and adequately.
2. Do not delay treatment for the arrival of medical personnel.
3. The effectiveness of treatment decreases with the length of time between the onset of symptoms and the treatment.
4. Do not ignore seemingly minor symptoms. They can quickly become major.
5. Follow the selected treatment table accurately and completely.
6. If a symptom—or group of symptoms—seems to be relieved, do not assume that the treatment is finished. Follow the tables to completion, and keep the diver in the immediate vicinity of the chamber (or the diving station) for at least 6 hours following recompression and within one-half hour travel time to the chamber for 24 hours.

No Recompression Chamber 8.4.1 In the event that the diving facility is not equipped with a recompression chamber, the Diving Supervisor has two alternatives. If recompression of the patient is not immediately necessary, he may be transported to the nearest recompression chamber for treatment. (The location of the nearest recompression chamber must be included in the data collected during the planning phase of the dive, Chapter Four).

If immediate recompression treatment is necessary, the patient must be treated in the water. The hazards involved in this procedure must be carefully weighed against the complications which may result if treat-

DIAGNOSIS OF DECOMPRESSION SICKNESS

SIGNS & SYMPTOMS	DECOMPRESSION SICKNESS: Skin	DECOMPRESSION SICKNESS: Pain Only	DECOMPRESSION SICKNESS, SERIOUS: CNS	DECOMPRESSION SICKNESS, SERIOUS: Chokes	GAS EMBOLISM, CNS SYMPTOMS: Brain Damage	GAS EMBOLISM, CNS SYMPTOMS: Spinal Cord Damage	GAS EMBOLISM: Pneumo-Thorax	GAS EMBOLISM: Mediastinal Emphysema
Pain-Head					■			
Pain-Back			□					
Pain-Neck								■
Pain-Chest			□	■		□	■	□
Pain-Stomach			■			□		
Pain-Arms/Legs		■				□		
Pain-Shoulders		■				□		
Pain-Hips		■				□		
Unconsciousness			■	□	■	□	□	
Shock			■	□	■	□	□	
Vertigo			■					
Visual Difficulty			■		■			
Nausea/Vomiting			■		■			
Hearing Difficulty			■		■			
Speech Difficulty			■		■			
Balance Lack			■		■			
Numbness	□		■		■	□		□
Weakness		□	■		■	□		
Strange Sensations	□		■		■	□		
Swollen Neck								■
Short of Breath			□	□	□	□	□	□
Cyanosis				□	□	□	□	□
Skin Changes	■							

■ Probable
□ Possible Cause

CONFIRMING INFORMATION

Diving History

	Yes	No
Decompression Obligation?	□	□
Decompression Adequate?	□	□
Blow-up?	□	□
Breath-hold?	□	□
Non-pressure Cause?	□	□
Previous Exposure?	□	□

Patient Examination	Yes	No
Does diver feel well?	□	□
Does diver look and act normal?	□	□
Does diver have normal strength?	□	□
Are diver's sensations normal?	□	□
Are diver's eyes normal?	□	□
Are diver's reflexes normal?	□	□
Is diver's pulse rate normal?	□	□
Is diver's gait normal?	□	□
Is diver's hearing normal?	□	□
Is diver's coordination normal?	□	□
Is diver's balance normal?	□	□
Does the diver feel nauseated?	□	□

Figure 8-4 Decompression Diagnosis Chart

ment is delayed. Except in grave emergencies, seek the nearest recompression chamber, even if it is at a considerable distance.

TRANSPORTING THE PATIENT 8.4.1.1 Not all patients will require immediate recompression—that is, a certain delay may be acceptable while the patient is transported to a recompression chamber. While preparing a patient for recompression (when a delay is necessary) and while moving him to a chamber, he should be kept lying down, feet slightly higher than his head, with his body tilted 20° to the left side. This position may help to keep bubbles away from the more critical sites. Additionally, the patient should be kept warm, and his condition must be constantly monitored for signs of a blocked airway, fainting, cardiac arrest, cessation of breathing or sudden massive internal bleeding. Always keep in mind that the most obvious symptoms may not actually be related to the most serious problem—a number of conditions may well exist at the same time. For example, the victim may be suffering from both decompression sickness and severe internal injuries.

If the patient must be transported, the initial arrangements should have been made well in advance of the actual diving operations. These arrangements—which would include an "alert" notification to the recompression chamber and a determination of the most effective means of transportation—should be posted on "Job-Site Emergency Check List" (see Chapter Four) for instant referral.

If the patient is moved by air, the helicopter or other aircraft should be flown as low as possible. Any unnecessary altitude means an additional reduction in external pressure and possible additional symptom severity or complications. While in transit, oxygen (if available) should be administered to the patient.

Have someone call ahead to ensure that the chamber will be ready, and that qualified medical personnel will be standing by. If two-way communications can be established, obtain consultation with the doctor while in transit.

IN-WATER RECOMPRESSION 8.4.1.2

A. If water recompression must be used and the diver is conscious and able to care for himself—

1. Use either a full face mask or, preferably a deep-sea diving outfit. Never recompress a a diver in the water using a SCUBA with a mouthpiece.
2. Follow treatment tables as closely as possible.
3. Maintain constant communication.

B. If the diver is unconscious or incapacitated, send another diver down with him to control his valves and otherwise assist him.

C. If a lightweight diving outfit or SCUBA (with full face mask) must be used, keep at least one diver with the patient at all times. Plan carefully for shifting rigs or cylinders. Have an ample number of tenders topside and at intermediate depths.

D. If the depth is inadequate for full treatment according to the tables—

1. Take the patient to maximum available depth.
2. Keep him there for 30 minutes.
3. Bring him up according to table 2A of the Treatment Table Using Air. Do not use stops shorter than those of table 2A.

Treatment Tables 8.4.2 Extensive research and field experience have shown the therapeutic value of oxygen administration during recompression treatment. The Oxygen Treatment Tables are the preferred procedure for recompression treatment. When employing the tables be particularly conscious of the early signs of O_2 toxicity which can be readily remembered by the acronym, VENTID—Vision, Ears, Nausea, Twitching, Irritability, Dizziness.

The Air Treatment Tables are not nearly as effective as the Oxygen Treatment Tables and should be employed only when oxygen is not available in the recompression chamber, if in-water recompression is necessitated, or in situations in which treatment using the Oxygen Treatment Tables are unsuccessful. In administering recompression treatment using either table, the rules specified in Table No. 8-1 should be fully complied with to avoid danger to the patient and attending personnel.

The maximum recompression depth employed in treatment is based upon the response of the patient's

Table 8-1
RULES FOR RECOMPRESSION TREATMENT

ALWAYS

1. Follow the Treatment Tables accurately.
2. Have qualified tender in chamber at all times during recompression.
3. Maintain the normal descent and ascent rates.
4. Examine patient thoroughly at depth of relief or treatment depth.
5. Treat an unconscious patient for gas embolism or serious decompression sickness unless the possibility of such a condition can be ruled out without question.
6. Consider the use of 80% helium-20% oxygen in cases of serious symptoms, recurrence of symptoms, or when patient has difficulty breathing.
7. Use oxygen if available.
8. Have a qualified diver accompany the patient in the chamber during treatment.
9. Be alert for oxygen poisoning if oxygen is used.
10. In the event of oxygen convulsion, remove the oxygen mask and keep the patient from harming himself.
11. Maintain oxygen usage within the time and depth limitations.
12. Check patient's condition before and after coming to each stop and during long stops.
13. Observe patient for at least 6 hours after treatment for recurrence of symptoms.
14. Maintain accurate timekeeping and recording.
15. Maintain a well stocked medical kit at hand.

NEVER

1. Permit any shortening or other alteration to the tables except under the direction of a trained Diving Medical Officer.
2. Exceed descent rate tolerated by the patient.
3. Let patient sleep between depth changes or for more than one hour at any one stop.
4. Continue ascent if patient's condition worsens.
5. Wait for a bag resusitator. Use mouth-to-mouth immediately if breathing ceases.
6. Break rhythm during resuscitation.
7. Permit the use of oxygen below 60 feet.
8. Fail to report symptoms early (diver).
9. Fail to treat doubtful cases.
10. Allow personnel in the chamber to assume any cramped position which may interfere with complete blood circulation.

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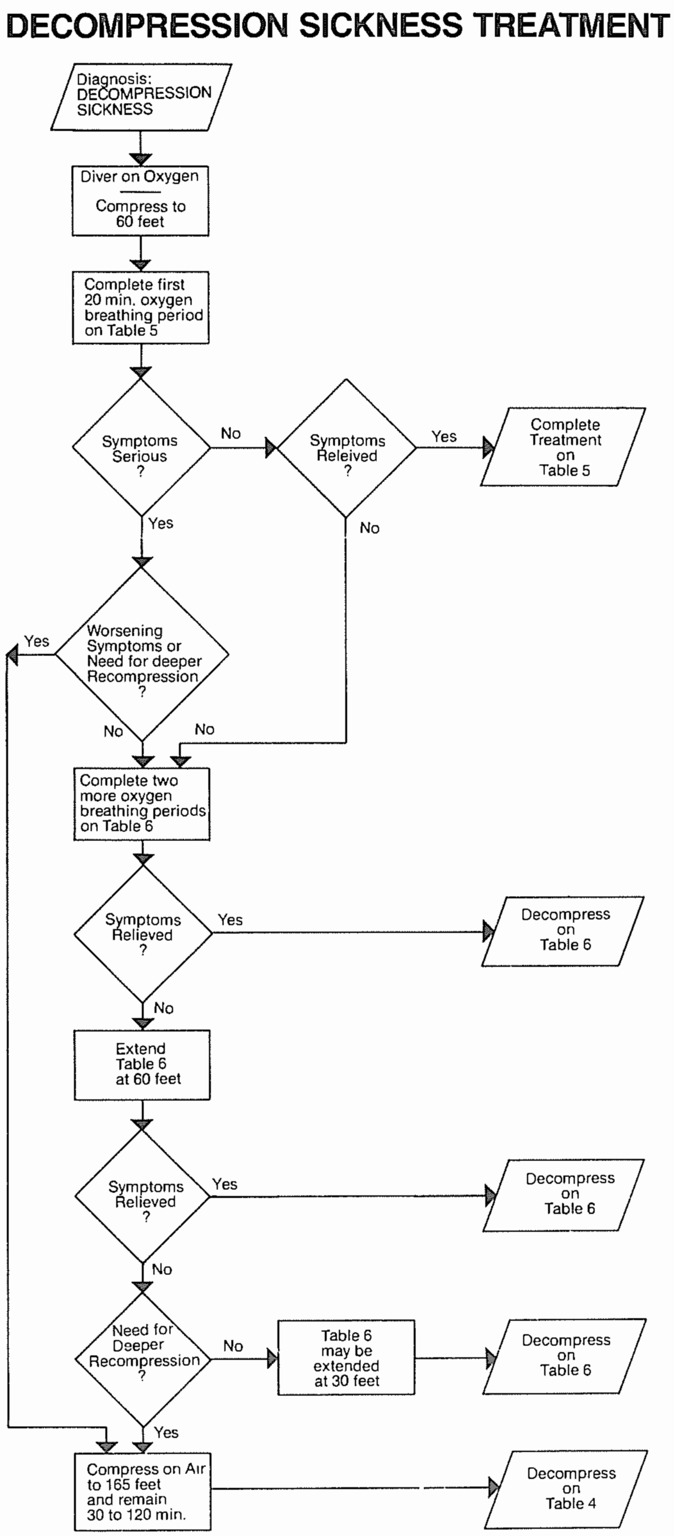
signs and symptoms to increasing pressure. Symptoms of decompression sickness and gas embolism normally respond quickly to repressurization, and a depth is reached (depth of relief—DOR) at which primary symptoms have subsided. Pressurization is continued until the shallowest standard recompression depth is reached—60, 100, or 165 feet—depending upon the table selected.

Following arrival at the required recompression depth, the patient's condition should be closely monitored. The patient is maintained at depth for the time period required on the applicable table. If symptoms persist, it may be necessary to extend the time period on the bottom or consider repressurization to greater depth. Either action will require selection of an alternate treatment table. Recompression below 165 feet should not be attempted except upon the direct advice of a diving medical officer since specialized decompression procedures will be required. Following the required time on the bottom, decompression is initiated following the specific schedule given in the appropriate table. During the decompression phase, the patient should be closely observed for a recurrence of symptoms which may necessitate immediate repressurization to relief depth and an alternate decompression procedure.

The Recompression Treatment Chart, Figure No. 8-5, has been developed to simplify administration of proper treatment. It's use is particularly helpful in situations in which a recurrence of symptoms occurs.



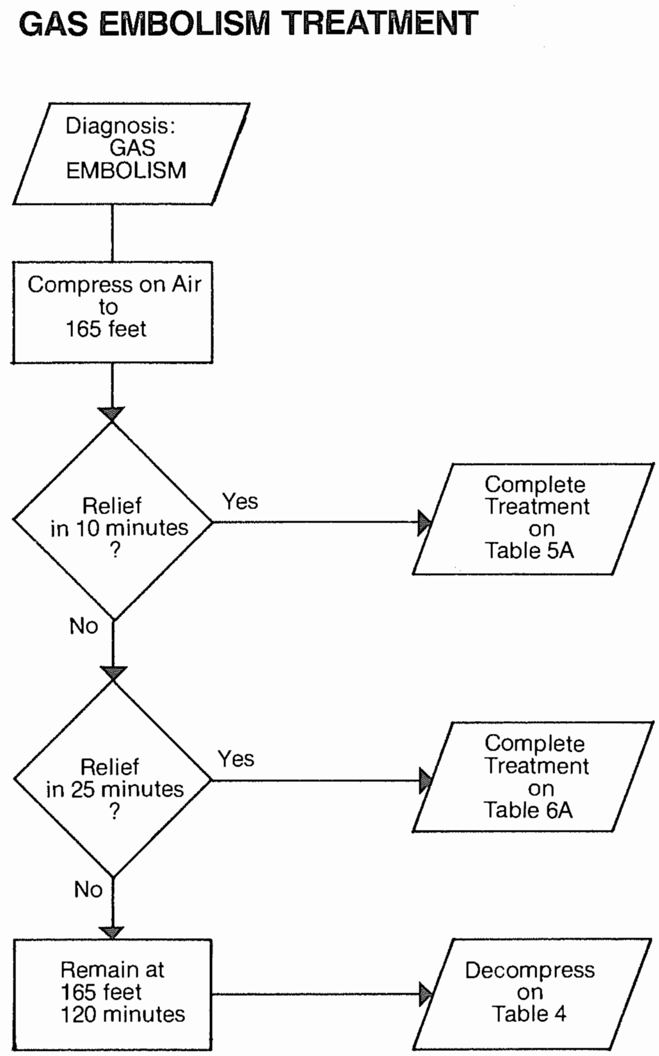


Figure 8-5 Decompression Sickness Treatment and Gas Embolism charts.

RECURRENCE DURING TREATMENT

RECURRENCE FOLLOWING TREATMENT

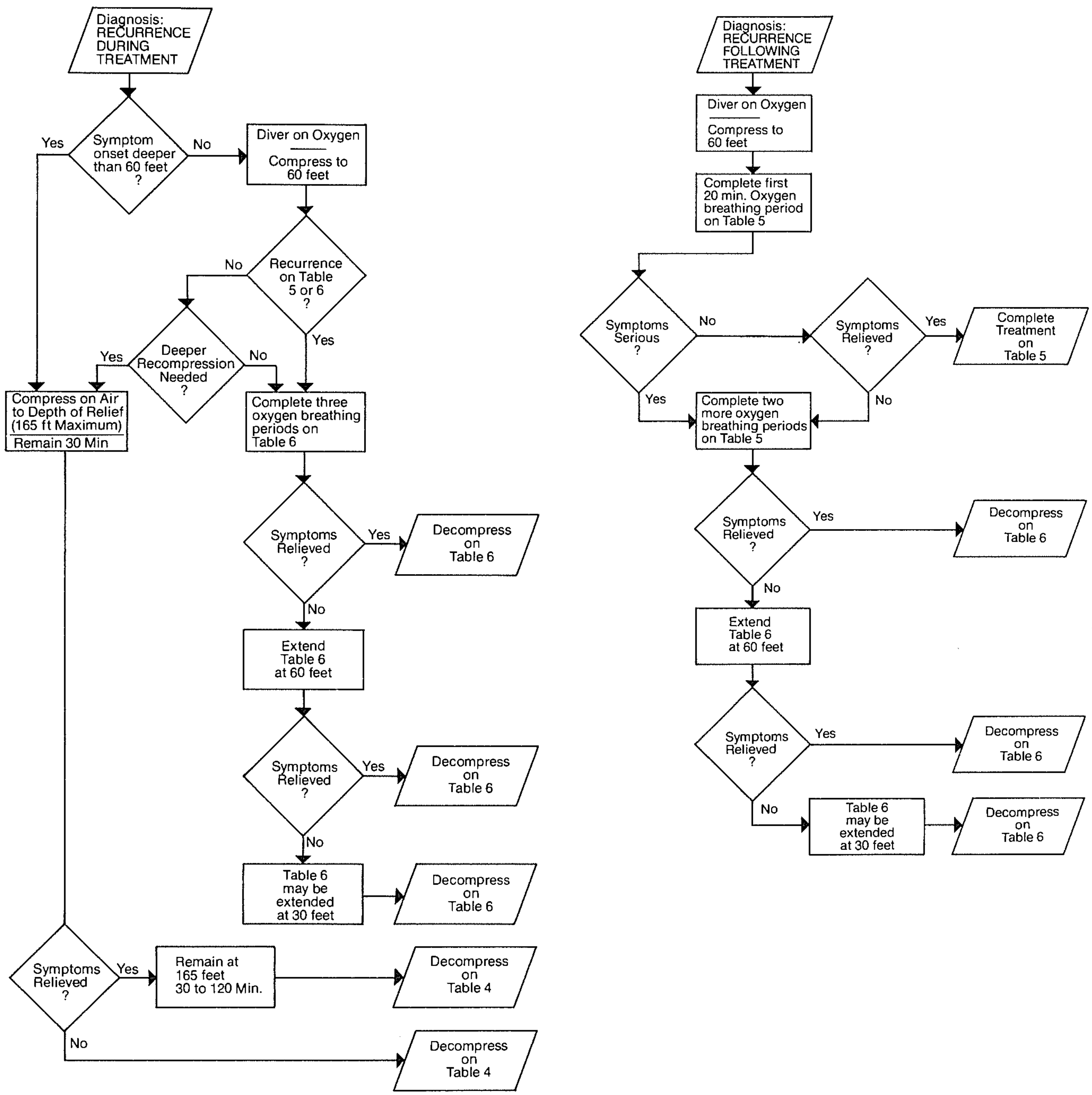


Figure 8-6 Recurrence During Treatment and Recurrence Following Treatment charts.

TABLE 1A—RECOMPRESSION TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM USING AIR

TABLE 1A NOTES—

1. Use—treatment of pain-only decompression sickness when oxygen cannot be used and pain is relieved at a depth less than 66 feet.
2. Descent rate—25 ft/min.
3. Ascent rate—1 minute between stops.
4. Time at 100 feet—includes time from the surface.

TABLE 1A

Depth (feet)	Time (minutes)	Breathing Media	Total Elapsed Time (minutes)
100	30	Air	30
80	12	Air	43
60	30	Air	74
50	30	Air	105
40	30	Air	136
30	60	Air	197
20	60	Air	258
10	120	Air	379
0	1	Air	380

TABLE 1A DEPTH/TIME PROFILE

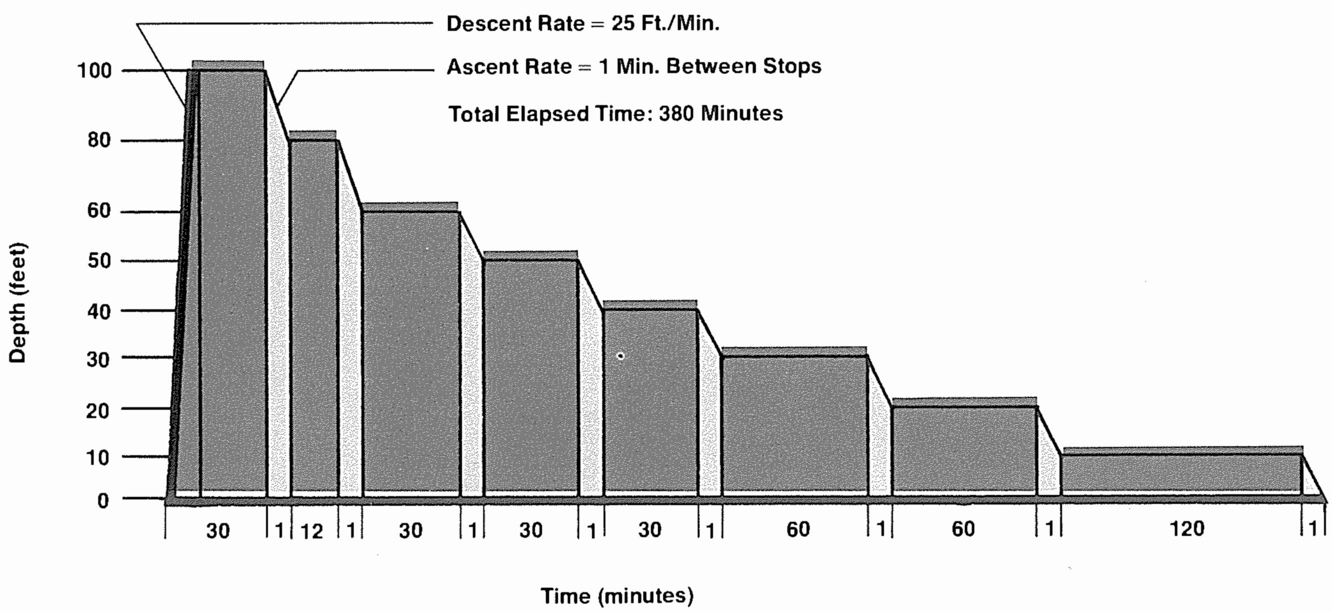


TABLE 2A—RECOMPRESSION TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM USING AIR

1. Use—treatment of pain-only decompression sickness when oxygen cannot be used and pain is relieved at a depth greater than 66 feet.
2. Descent rate—25 ft/min.
3. Ascent rate—1 minute between stops.
4. Time at 165 feet—includes time from the surface.

Depth (feet)	Time (minutes)	Breathing Media	Total Elapsed Time (minutes)
165	30	Air	30
140	12	Air	43
120	12	Air	56
100	12	Air	69
80	12	Air	82
60	30	Air	113
50	30	Air	144
40	30	Air	175
30	120	Air	296
20	120	Air	417
10	240	Air	658
0	1	Air	659

TABLE 2A DEPTH/TIME PROFILE

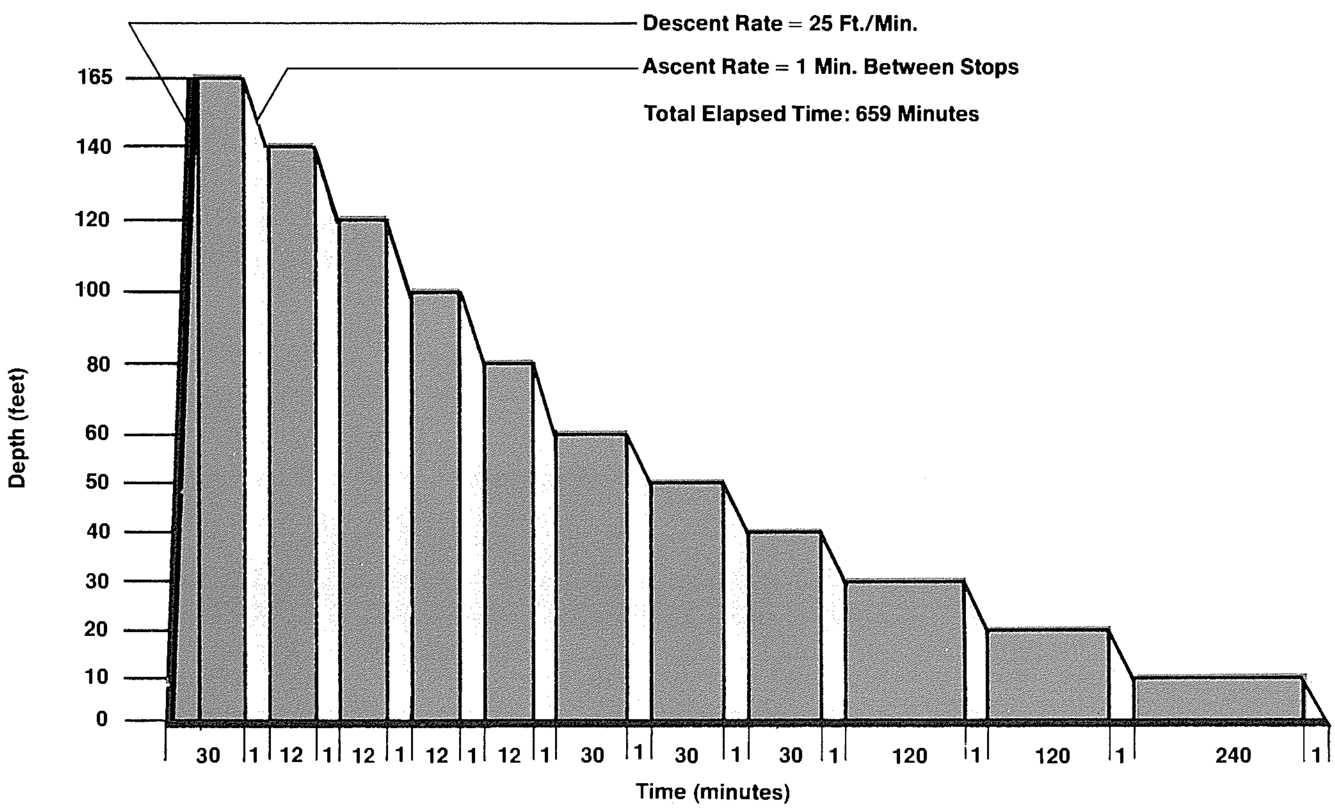


TABLE 3—RECOMPRESSION TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM USING AIR

1. Use—treatment of serious symptoms when oxygen cannot be used and symptoms are relieved within 30 minutes at 165 feet.
2. Descent rate—as fast as possible.
3. Ascent rate—1 minute between stops.
4. Time at 165 feet—includes time from the surface.

Depth (feet)	Time	Breathing Media	Total Elapsed Time (hrs:min)
165	30 min.	Air	0:30
140	12 min.	Air	0:43
120	12 min.	Air	0:56
100	12 min.	Air	1:09
80	12 min.	Air	1:22
60	30 min.	Oxygen (or air)	1:53
50	30 min.	Oxygen (or air)	2:24
40	30 min.	Oxygen (or air)	2:55
30	12 hr.	Air	14:56
20	2 hr.	Air	16:57
10	2 hr.	Air	18:58
0	1 min.	Air	18:59

TABLE 3 DEPTH/TIME PROFILE

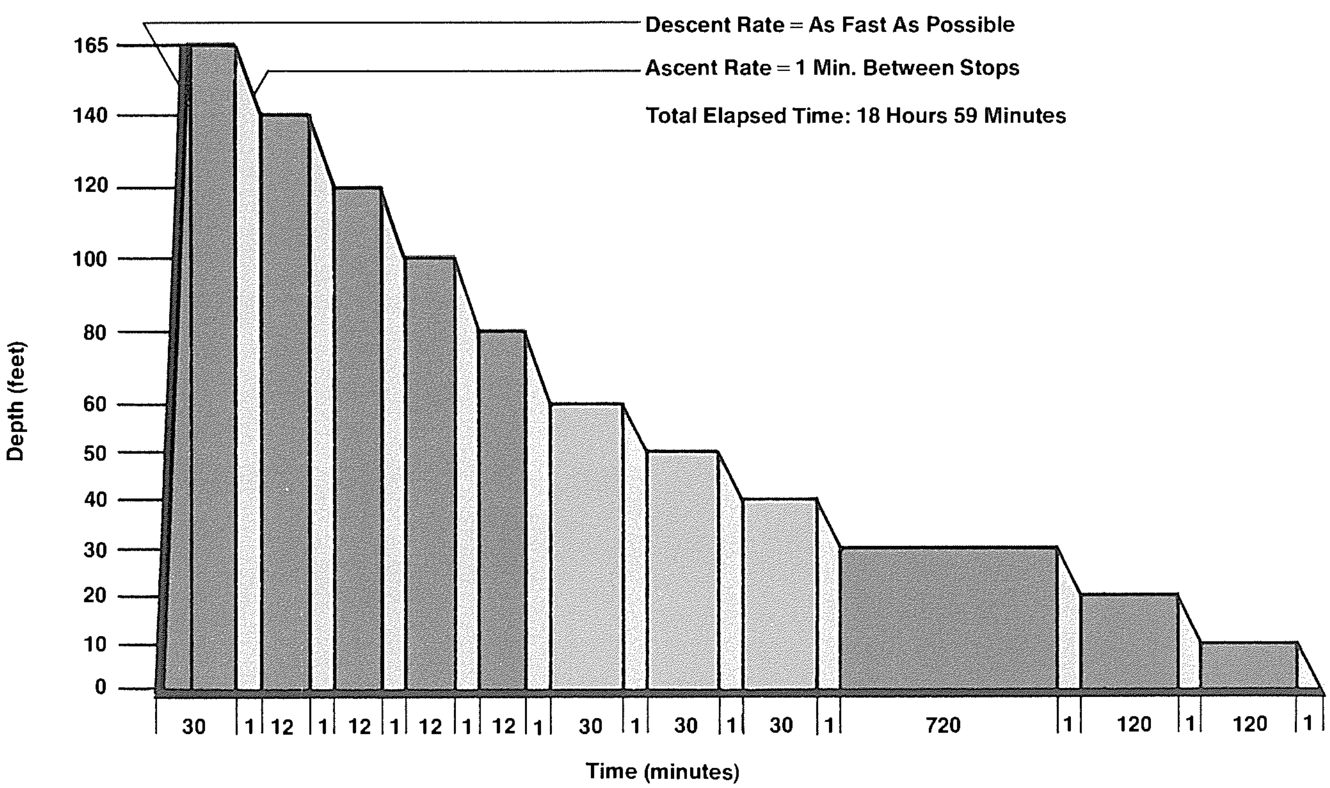


TABLE 4—RECOMPRESSION TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM USING AIR

1. Use—treatment of serious symptoms or gas embolism when oxygen cannot be used and when symptoms are not relieved within 30 minutes at 165 feet.
2. Descent rate—as fast as possible.
3. Ascent rate—1 minute between stops.
4. Time at 165 feet—includes time from the surface.

Depth (feet)	Time	Breathing Media	Total Elapsed Time (hrs:min)
165	½ to 1½ hr.	Air	1:30
140	½ hr.	Air	2:01
120	½ hr.	Air	2:32
100	½ hr.	Air	3:03
80	½ hr.	Air	3:34
60	6 hr.	Air	9:35
50	6 hr.	Air	15:36
40	6 hr.	Air	21:37
30	11 hr.	Air	32:38
30	1 hr.	Oxygen (or air)	33:38
20	1 hr.	Air	34:39
20	1 hr.	Oxygen (or air)	35:39
10	1 hr.	Air	36:40
10	1 hr.	Oxygen (or air)	37:40
0	1 min.	Oxygen	37:41

TABLE 4 DEPTH/TIME PROFILE

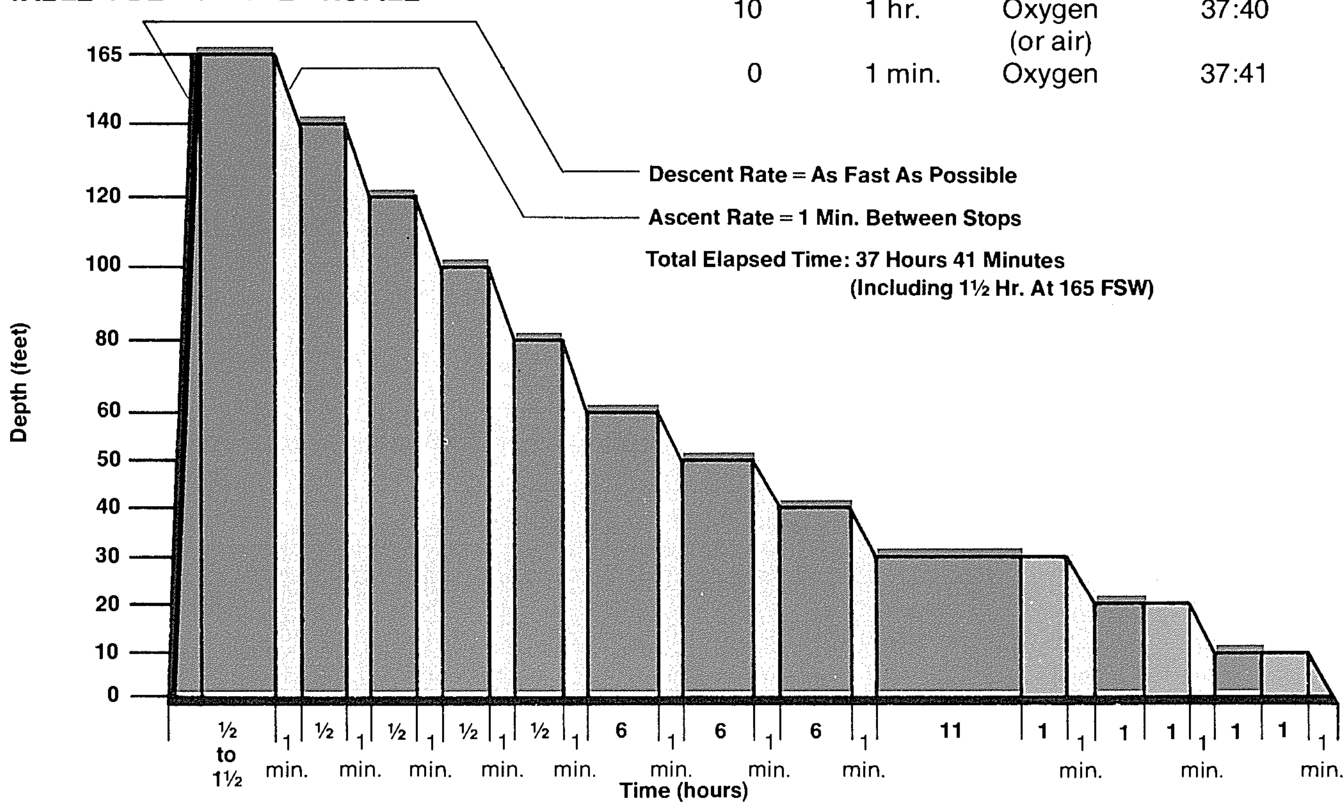


TABLE 5—MINIMAL RECOMPRESSION, OXYGEN BREATHING METHOD FOR TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM

1. Use—treatment of pain-only decompression sickness when oxygen can be used and symptoms are relieved within 10 minutes at 60 feet. Patient breathes oxygen from the surface.
. Descent rate—25 ft/min.
3. Ascent rate—1 ft/min. Do not compensate for slower ascent rates. Compensate for faster rates by halting the ascent.
4. Time at 60 feet begins on arrival at 60 feet.
5. If oxygen breathing must be interrupted, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption.
6. If oxygen breathing must be interrupted at 60 feet, switch to TABLE 6 upon arrival at the 30 foot stop.
7. Tender breathes air throughout. If treatment is a repetitive dive for the tender or tables are lengthened, tender should breathe oxygen during the last 30 minutes of ascent to the surface.

Depth (feet)	Time (minutes)	Breathing Media	Total Elapsed Time (minutes)
60	20	Oxygen	20
60	5	Air	25
60	20	Oxygen	45
60 to 30	30	Oxygen	75
30	5	Air	80
30	20	Oxygen	100
30	5	Air	105
30 to 0	30	Oxygen	135

TABLE 5 DEPTH/TIME PROFILE

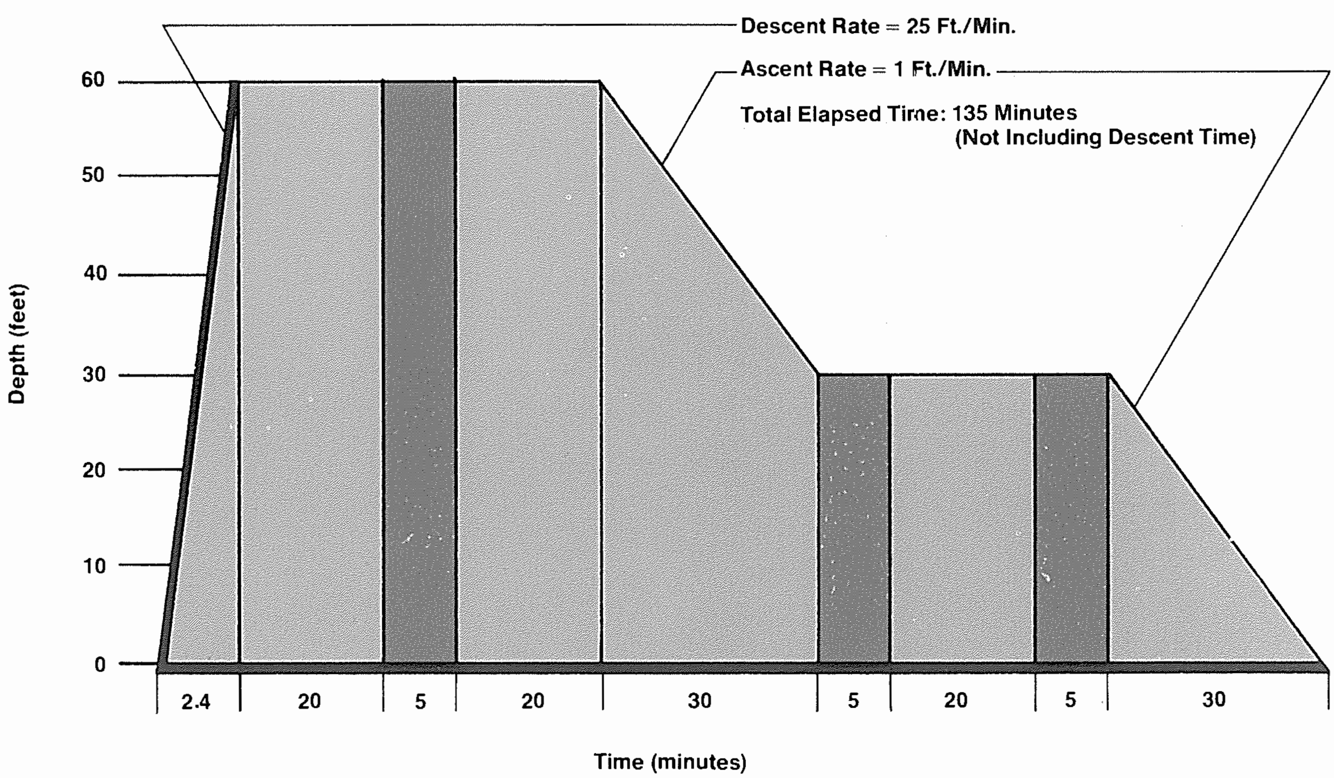


TABLE 6—MINIMAL RECOMPRESSION, OXYGEN BREATHING METHOD FOR TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM

1. Use—treatment of decompression sickness when oxygen can be used and symptoms are not relieved within 10 minutes at 60 feet. Patient breathes oxygen from the surface.
2. Descent rate—25 ft/min.
3. Ascent rate—1 ft/min. Do not compensate for slower ascent rates. Compensate for faster rates by halting the ascent.
4. Time at 60 feet—begins on arrival at 60 feet.
5. If oxygen breathing must be interrupted, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption.
6. Tender breathes air throughout. If treatment is a repetitive dive for the tender or tables are lengthened, tender should breathe oxygen during the last 30 minutes of ascent to the surface.

Depth (feet)	Time (minutes)	Breathing Media	Total Elapsed Time (minutes)
60	20	Oxygen	20
60	5	Air	25
60	20	Oxygen	45
60	5	Air	50
60	20	Oxygen	70
60	5	Air	75
60 to 30	30	Oxygen	105
30	15	Air	120
30	60	Oxygen	180
30	15	Air	195
30	60	Oxygen	255
30 to 0	30	Oxygen	285

TABLE 6 DEPTH/TIME PROFILE

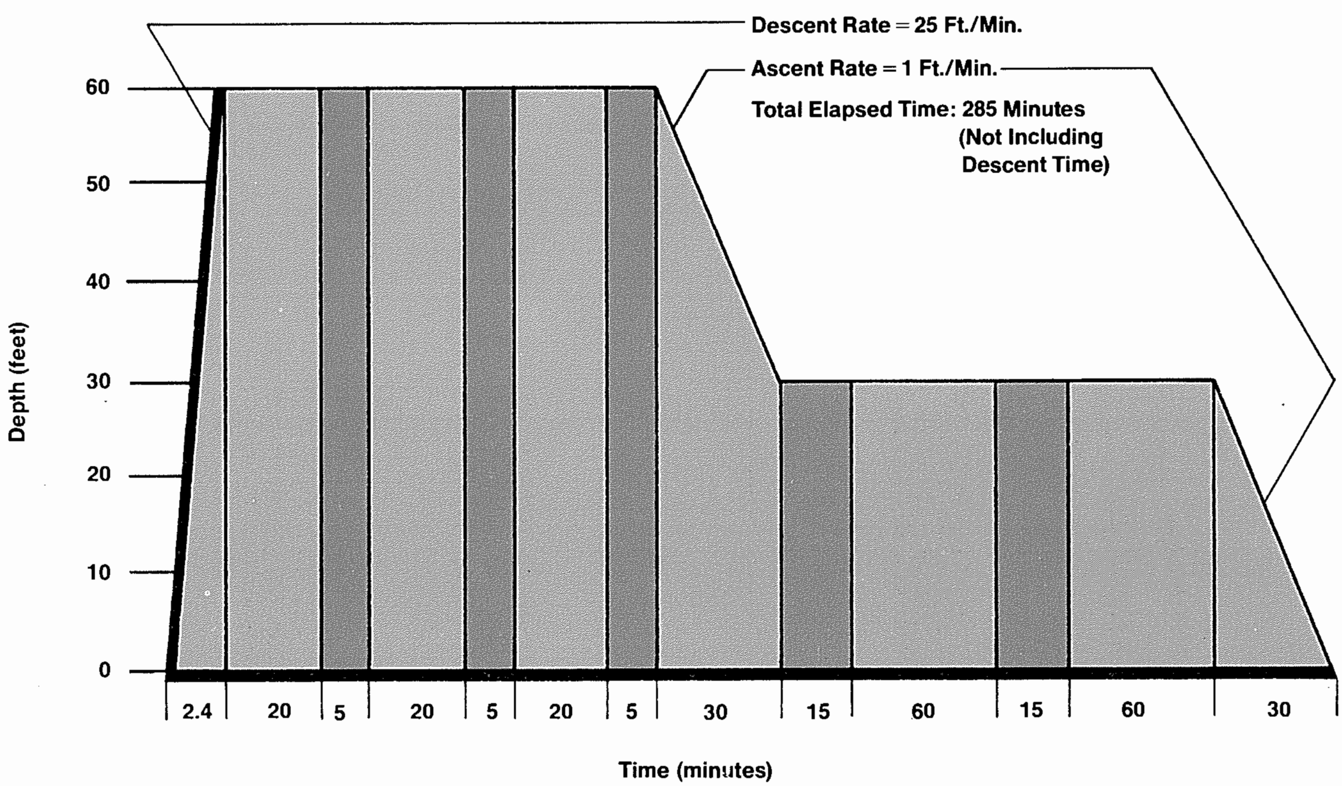


TABLE 5A—MINIMAL RECOMPRESSION, OXYGEN BREATHING METHOD FOR TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM

1. Use—treatment of gas embolism when oxygen can be used and symptoms are relieved within 15 minutes at 165 feet.
2. Descent rate—as fast as possible.
3. Ascent rate—1 ft/min. Do not compensate for slower ascent rates. Compensate for faster ascent rates by halting the ascent.
4. Time at 165 feet—includes time from the surface.
5. If oxygen breathing must be interrupted, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption.
6. Tender breathes air throughout. If treatment is a repetitive dive for the tender or tables are lengthened, tender should breathe oxygen during the last 30 minutes of ascent to the surface.

Depth (feet)	Time (minutes)	Breathing Media	Total Elapsed Time (minutes)
165	15	Air	15
165 to 60	4	Air	19
60	20	Oxygen	39
60	5	Air	44
60	20	Oxygen	64
60 to 30	30	Oxygen	94
30	5	Air	99
30	20	Oxygen	119
30	5	Air	124
30 to 0	30	Oxygen	154

TABLE 5A DEPTH/TIME PROFILE

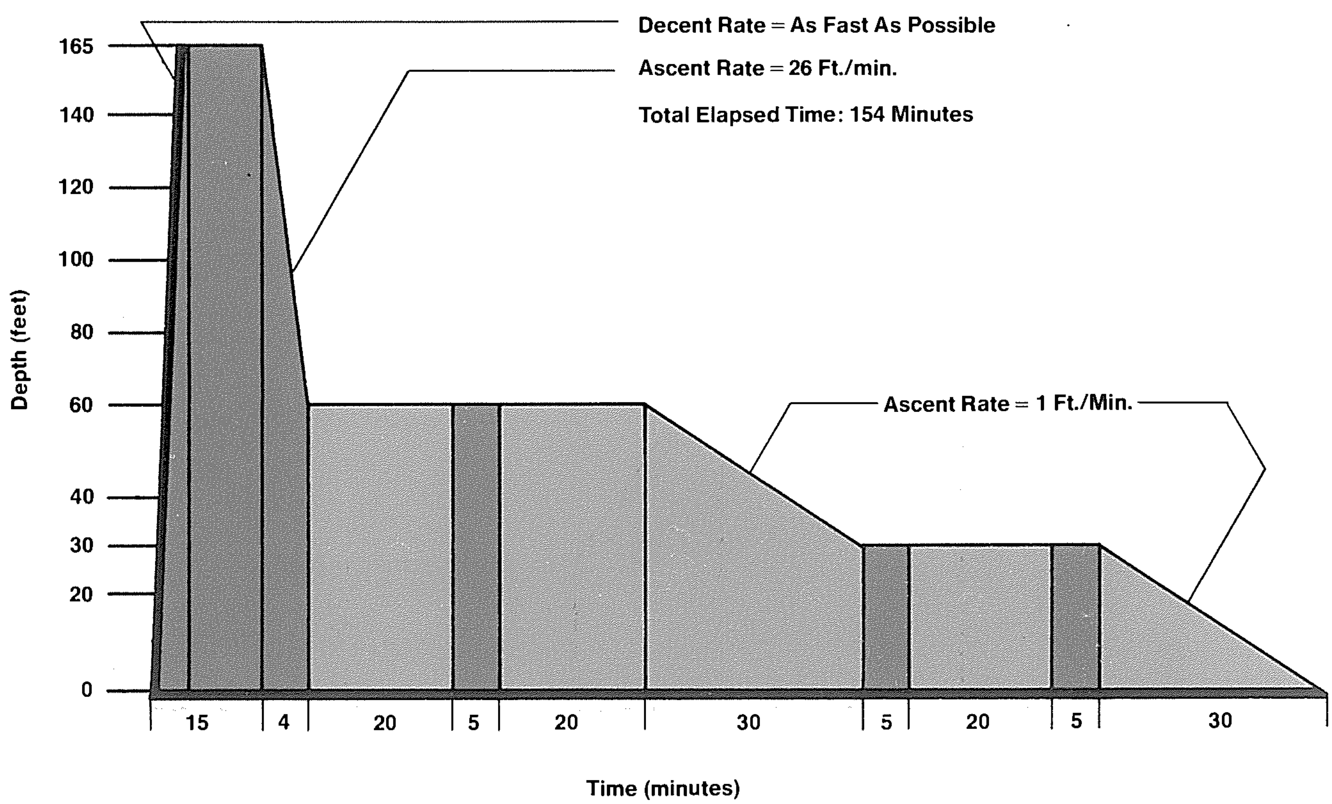
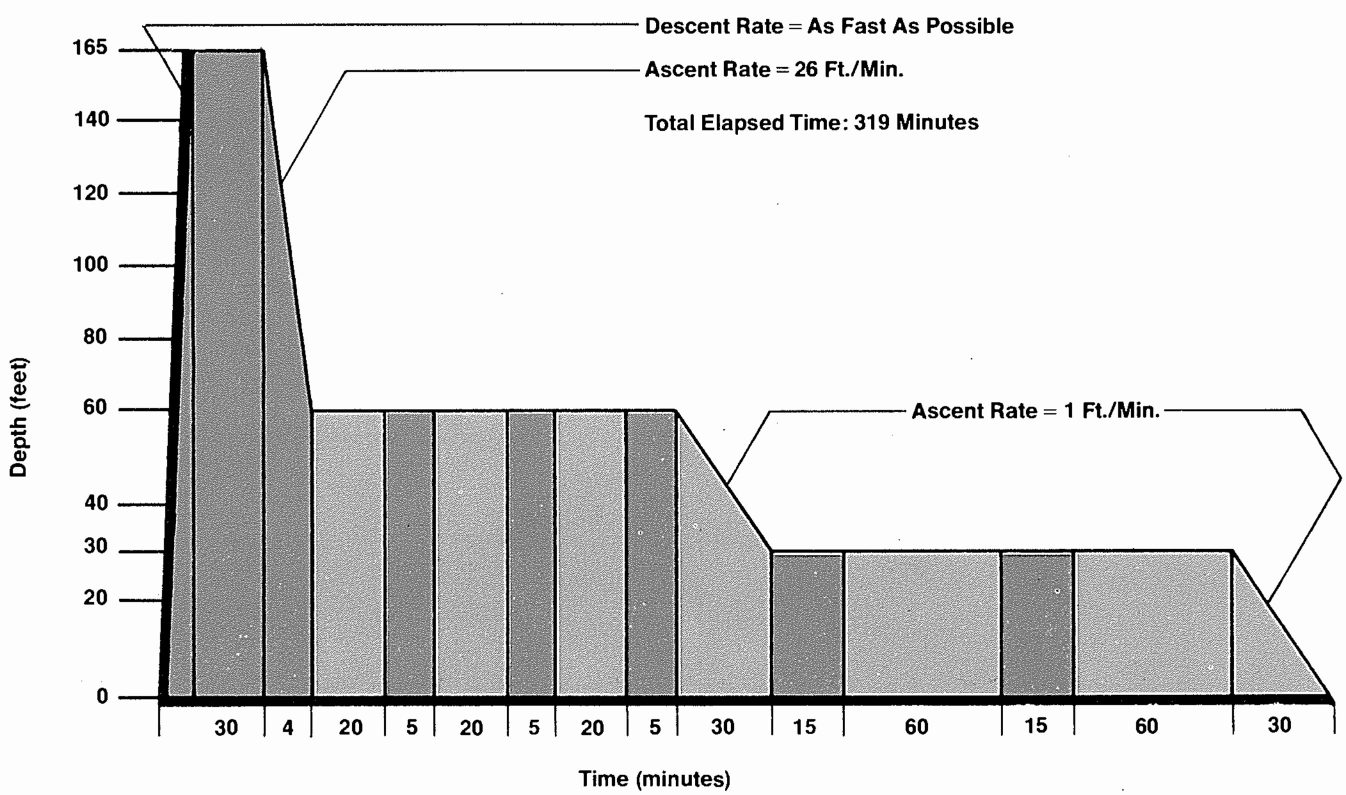


TABLE 6A—MINIMAL RECOMPRESSION, OXYGEN BREATHING METHOD FOR TREATMENT OF DECOMPRESSION SICKNESS AND GAS EMBOLISM

1. Use—treatment of gas embolism when oxygen can be used and symptoms moderate to a major extent within 30 minutes at 165 feet.
2. Descent rate—as fast as possible.
3. Ascent rate—1 ft/min. Do not compensate for slower ascent rates. Compensate for faster ascent rates by halting the ascent.
4. Time at 165 feet—includes time from the surface.
5. If oxygen breathing must be interrupted, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption.
6. Tender breathes air throughout. If treatment is a repetitive dive for the tender or tables are lengthened, tender should breathe oxygen during the last 30 minutes of ascent to the surface.

Depth (feet)	Time (minutes)	Breathing Media	Total Elapsed Time (minutes)
165	30	Air	30
165 to 60	4	Air	34
60	20	Oxygen	54
60	5	Air	50
60	20	Oxygen	79
60	5	Air	84
60	20	Oxygen	104
60	5	Air	109
60 to 30	30	Oxygen	139
30	15	Air	154
30	60	Oxygen	214
30	15	Air	229
30	60	Oxygen	289
30 to 0	30	Oxygen	319

TABLE 6A DEPTH/TIME PROFILE



Recompression Chamber 8.4.3 Recompression chambers are furnished by NAVSHIPS and NAVFAC to ships and shore facilities, respectively, which regularly conduct diving operations. Recompression chambers are not only used for the treatment of decompression sickness and surface decompression, but also for administering pressure and oxygen tolerance tests for divers and prospective divers. In other than diving applications, suitable chambers may be found being used for medical treatment (both routine and emergency), in research laboratories, and in military and commercial aviation schools and operating facilities.

Table No. 8-2 lists those places, both military and civilian, where a chamber may possibly be located. This list may prove useful while planning for an operation since the diving team must always know the location and type of the nearest chamber before the operation begins.

The type, size and utility of recompression chambers found at such diverse locations will, of course, vary widely. As long as the chamber is large enough to hold the patient and keep him under reasonable pressure, its use should not be ruled out.

TABLE 8-2 POSSIBLE LOCATIONS OF SUITABLE RECOMPRESSION CHAMBERS*

Tenders	Harbor clearance units
Salvage vessels	Torpedo stations
Submarine rescue vessels	Air Force hospitals
Repair ships	NASA facilities
Fleet tugs (some)	Army Corps of Engineers facilities
Naval shipyards	
Major naval bases	FAA facilities
Naval air stations	VA hospitals
Submarine bases	Civilian
Diving schools	Research laboratories
EOD Units	Universities
UDT Units	Commercial diving firms and schools
Research laboratories	
Test ranges	

*A complete lising of available recompression chambers is given in the Directory of World Wide, Shore Based Hyperbaric Chambers, NAVSHIPS 0994-010-4012.

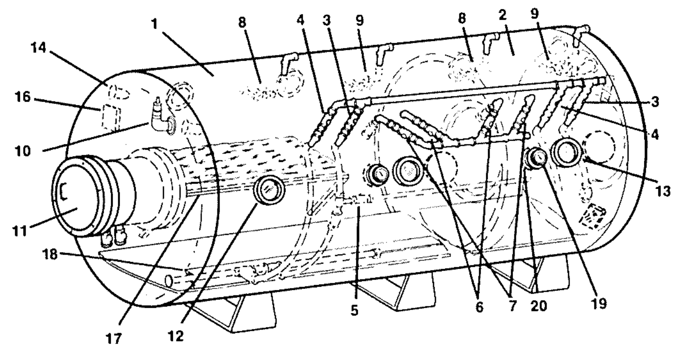
DESCRIPTION OF CHAMBERS 8.4.3.1 Most chamber-equipped U.S. Navy units will have one of three commonly provided chambers designed for permanent installation. They are—

—Two-lock, 200 psi, 500 cubic foot chamber

—Two-lock, 100 psi, 227 cubic foot aluminum chamber

—One-lock, 100 psi, 250 cubic foot chamber

Two-lock chambers are highly desirable because they permit tending personnel to enter and leave the chamber during treatment. With a one-lock unit, the tender or medical attendant must remain with the patient throughout the course of treatment and cannot be relieved or assisted. However, all regular chambers are provided with a medical lock for passing small objects, such as food and medical supplies, in and out of the chamber.



1. **Inner Lock**
2. **Outer Lock**
3. **Air Supply-Two Valve**
4. **Air Supply-One Valve**
5. **Main Lock Pressure Equalizing Valve**
6. **Exhaust-Two Valve**
7. **Exhaust-One Valve**
8. **Oxygen Manifold**
9. **Helium-Oxygen Manifold**
10. **Relief Valve-200 psig**
11. **Medical Lock-18 18 inch dia.**
12. **Viewport-inner lock (4)**
13. **Viewport-outer lock (2)**
14. **Lights-inner lock 60 watt (4)**
15. **Lights-outer lock 60 watt (4)**
16. **Transmitter-Receiver (2)**
17. **Berth-2′6″ x 6′6″**
18. **Bench**
19. **Pressure Gage-outside (4)**
20. **Pressure Gage-inside (4)**

Design Pressure—200 psig

Original Hydrostatic Test Pressure—400 psig

Principal Location—Submarine rescue ships and submarine tenders

Figure 8-7 Phantom view of two-lock recompression chamber.

The basic components of a recompression chamber are much the same from one model to another, and certain design specifications apply to all Navy approved chambers. They must be able to impose and maintain a pressure equivalent to a depth of 165 feet (6 atmospheres absolute). All piping and valving should be arranged to permit control of the air supply and the exhaust (for both locks in a two-lock chamber) from either the inside or the outside of the chamber, Figure No. 8-8. Controls on the outside must be able to override the inside controls, a most important feature in the event of an accident or serious problem inside the chamber. The usual method for providing this dual-control capability is through the use of two separate systems. The first, consisting of a supply line and an exhaust line, can only be controlled by valves which are outside of the chamber. The second supply/exhaust system has a double set of valves, one inside and one outside the chamber. This arrangement permits the tender to regulate descent or ascent from within the chamber, but always subject to final control by outside personnel.

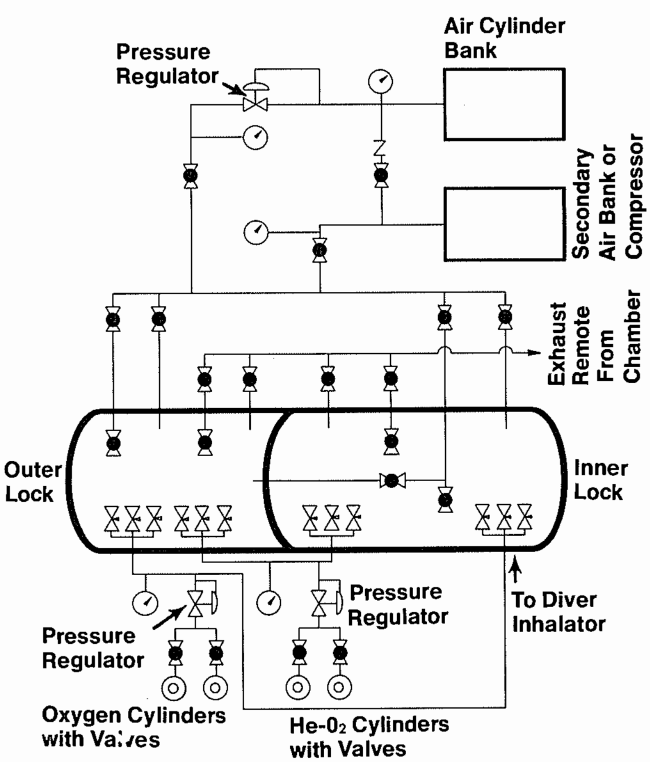


Figure 8-8 Recompression chamber gas supply schematic.

All lines should be identified and labeled to indicate function, content, maximum pressure and direction of flow. The color coding of MIL-STD-101B should be used with the following additions—

Gas Systems	Designation	Paint Color
Helium	He	Buff
Oxygen	O_2	Green
Helium-Oxygen Mix	He-O_2	Orange
Nitrogen	N	Light gray
Exhaust	E	Silver
Air low or high pressure	ALP, AHP	Black

Optimum chamber ventilation requires maximum separation of the inlet and exhaust ports within the chamber. Exhaust ports should be guarded to prevent accidental body contact and associated injury when they are open.

All chambers must be fitted with appropriate pressure gages both inside and outside at the control stations. These gages, marked to read in "feet of seawater," must be calibrated to ensure accuracy every 12 months in accordance with the instructions in Appendix H.

Chamber communications may be provided through an approved diver's amplifier, with the dual microphone/reproducer unit in the chamber and the control panel outside. The communication system should be arranged so that personnel inside the chamber need not interrupt their activities to operate the system. A back-up communications system (which should always be installed) is best provided by a set of standard sound-powered telephones. The "press-to-talk" button on the set inside the chamber can be taped down, thus keeping the circuit always "open."

Because of the possibility of fire or explosion when working in an oxygen or compressed air atmosphere, all electrical wiring and equipment used in a chamber must meet rigid specifications. All wiring must be heavy-duty, armored or in a conduit. All switches must be located outside the chamber. All lighting fixtures must be pressure-proof, and should be permanently installed; fluorescent fixtures must never be used.

Consideration should be given to installation of a low-level lighting fixture (on a separate circuit) which can be used to relieve the patient of the heat and glare of the main lights.

Any electrical equipment other than lights or emergency medical apparatus (if properly designed for use in a chamber) is prohibited. In a permanently installed chamber, heat can be provided through the use of a steam or hot-water radiator system

CHAMBER GAS SUPPLY 8.4.3.2 A primary and secondary air supply must be provided for every recompression chamber. The primary supply, most often a cylinder bank, should contain enough air to pressurize the chamber to its working pressure at least twice. The chart below, Figure No. 8-9, indicates the recommended number of gas cylinders, containing 200 SCF each, to adequately support most U. S. Navy recompression chambers. The secondary air supply, usually a compressor, should be capable of pressurizing the chamber to its working pressure at a minimum rate of 50 feet per minute and maintaining adequate ventilation at bottom pressure. The compressor should not be connected directly to the chamber because of temperature problems. It should be connected to an accumulator or cylinder bank to permit air cooling prior to chamber use. It, or still another compressor, should also be capable of charging the primary air supply cylinder bank at a reasonably rapid rate. The air itself must be free of oil, other foreign matter, objectionable gases and odors as discussed in Chapter Six.

Recompression chambers should be equipped with a means for delivering breathing oxygen to the patient in the main chamber. It may be useful if the oxygen can also be provided to the outer lock where it will help in decompression of tenders who are leaving the chamber before the patient has been fully decompressed.

The inner lock should be provided with connections for three or more demand-type oxygen inhalators. Oxygen can be furnished through a high-pressure manifold connected with supply cylinders (a minimum of two to permit interchange) outside the chamber. A medium pressure regulator must be located between the manifold and the thru-hull penetrator of the chamber. The standard Navy demand inhalator (FSN IH 4220-240-7150) is equipped with a demand regulator.

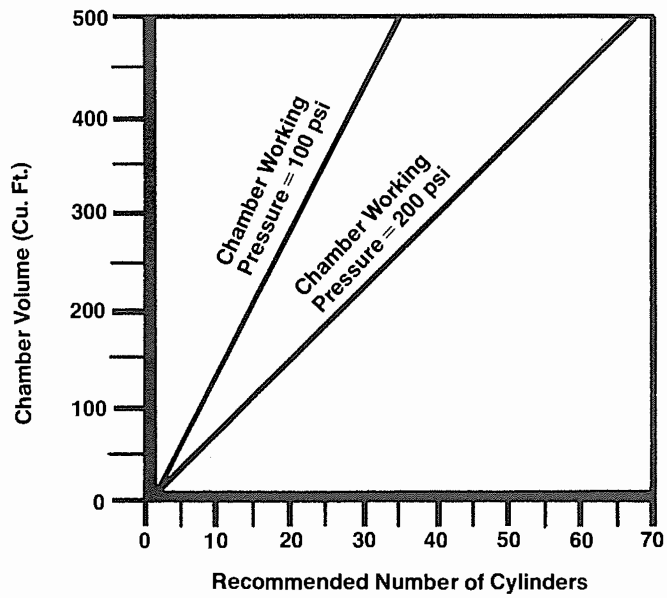


Figure 8-9 High pressure cylinder requirements

Non-standard oxygen breathing devices must not be used. Helium-oxygen (80%, 20%) is often useful in treating decompression sickness. A separate helium-oxygen cylinder manifold, associated piping, and manifold connections for use with inhalators is a mandatory requirement on ships equipped for He-O_2 diving. On other chambers the oxygen supply system can be modified to include He-O_2 by addition of a purge valve.

PREPARATION OF THE CHAMBER 8.4.3.3. A recompression chamber, like any piece of emergency equipment, must be kept in a state of instant readiness. The chamber must be in good repair, well maintained, and equipped with all necessary accessory equipment. A chamber is not a spare compartment for use. The chamber and the air and oxygen supply systems should be checked prior to use and on a regular monthly basis in accordance with the procedure in Table No. 8-3. All diving personnel must be trained in the operation of the recompression equipment and must be able to perform any task required during treatment.

The greatest single hazard in the use of a recompression chamber is from explosive fire. Fire may propagate 2 to 6 times faster than at atmospheric conditions because of the high partial pressure of oxygen in the

TABLE 8-3
RECOMPRESSION CHAMBER CHECKOUT PROCEDURE

Prior to each recompression treatment, and at monthly intervals, the following checkout should be conducted:

Chamber

1. ☐ Clean.
2. ☐ Free of all extraneous gear.
3. ☐ Free of noxious odors and/or contaminants.
4. ☐ Medical kit stocked and accessible.
5. ☐ Doors and door seals undamaged, properly installed and lubricated.

Ventilation System

1. ☐ Valves required for ventilation properly calibrated to indicate the number of turns vs. air volume flow.

Air Supply

1. ☐ Primary supply; enough air to pressurize chamber to working pressure twice.
2. ☐ Secondary supply operational.
3. ☐ Fittings, tight, filters clean, valves properly positioned, gages calibrated.

Oxygen Supply

1. ☐ Cylinders full and identified as "breathing oxygen."
2. ☐ Masks installed; inhalators functioning.
3. ☐ Fittings tight, filters clean, valves properly positioned, gages calibrated.
4. ☐ Oxygen elimination system, if installed, operational.

Helium-Oxygen Supply

1. ☐ Cylinders full.
2. ☐ Fittings tight, filters clean, valves properly positioned, gages calibrated.
3. ☐ Masks installed, inhalators functioning.

Electrical System

1. ☐ Lights operative.
2. ☐ Properly grounded; wiring approved.
3. ☐ Monitoring equipment calibrated and operational.

Communication System

1. ☐ Primary system operational.
2. ☐ Secondary system operational.

Fire Prevention System

1. ☐ Extinguishing system, if installed, charged and operational.
2. ☐ Water and sand buckets in chamber.
   proof jackets.
3. ☐ All combustible material enclosed in fireproof jackets.
4. ☐ No chemical fire extinguishers inside chamber.

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chamber atmosphere. The following precautions must be taken to minimize fire hazard—

1. Remove any fittings or equipment which do not conform with the standard requirements for the electrical system (as previously described) or which are made of any flammable materials. Permit no wooden deck gratings, benches or shelving in the chamber—replace them with metal or other fireproof material.

2. Equip the chamber with flameproof bedding material; if a mattress is used, ensure that it is completely enclosed in a flameproof cover or sheeting. Do not put any more bedding in a chamber than is necessary for the comfort of the patient, and never use blankets of wool or synthetic fibers because of the possibility of sparks from static electricity. Appropriate bedding can be obtained through the Navy supply system (FSN-9Q-7210-177-4986 or FSN 9P-7210-054-7911).

3. Only fire-retarding paint (FSN-8010-577-4739-2875 or equal) may be used in a chamber. If there is any doubt as to the type of paint that has previously been used, the chamber should be cleaned down to bare metal and repainted. Use one coat of primer TT-P-645 (FSN-8010-165-8557) and one coat of white MIL-P-17970 (FSN-8010-577-4739) for chamber interior surfaces. Exterior surfaces are to be given one coat of primer and two coats of white or gray per MIL-E-17972. After painting, do not use the chamber until the paint is thoroughly dry and all volatile vapors have been removed from the chamber. Repainting requires removal of the existing paint down to bare metal.

4. Keep oil and volatile materials out of the chamber. If any have been used, ensure that the chamber is thoroughly ventilated before pressurization. Do not put oil on or in any fittings or high-pressure line; and if for any reason oil is spilled in the chamber or soaked into any chamber surface or equipment, it must be completely removed. If lubricants are required, use only those approved and listed in NAVSHIPS 9230. Regularly inspect and clean air filters and accumulators in the air supply lines to protect against the introduction of oil or other vapors into the chamber. Permit no one to wear oily clothing into the chamber.

5. Never permit anyone to carry smoking materials, matches or lighters into a chamber, even if he does not intend to use them. A warning sign (Figure No. 8-10) should be posted inside and outside the chamber.

6. The chamber must be equipped with appropriate fire-fighting materials such as buckets of water and sand. Fire extinguishers containing carbon tetrachloride, CO_2, or dry powder must never be used. These chemicals are toxic in confined, pressurized atmospheres.

WARNING
FIRE/EXPLOSION HAZARD
No matches, lighters,
electrical appliances
or flammable materials
permitted in chamber

Figure 8-10 Fire/Explosion Warning Sign for recompression chamber

CHAMBER VENTILATION 8.4.3.4 Rules for ventilation are presented in Table No. 8-5, Chamber Operating Procedures. These rules permit rapid computation of the number of cubic feet of air per minute as measured at chamber pressure required under different conditions. (The rules are designed to assure that the effective concentration of carbon dioxide will not exceed 1.5 percent (11.4 mmHg) and that when oxygen is being used, the true percentage of oxygen in the chamber will not exceed 25 percent). If continuous analysis of oxygen is available, the chamber should be ventilated to keep the oxygen percentage below 22.5 percent in order to reduce fire hazard. For example, if the rules call for 4 cubic feet per minute, the chamber can be flushed continuously at a steady rate of 4 cubic feet per minute.

Setting Valves 8.4.3.4.1 Knowledge of the amount of air that must be used does not solve the ventilation problem unless there is some way to determine the volume of air actually being used for ventilation. The standard procedure is to open the exhaust valve a given number of turns (or fraction of a turn), which provides a certain number of cubic feet of ventilation per minute at a specific chamber pressure, and to use the control valve to maintain a constant chamber pressure during the ventilation period. Determination of valve settings required for different amounts of ventilation at different depths is accomplished as follows—

A. Mark the valve handle so that it is possible to determine fairly accurately the number of turns and fractions of turns.

B. Check the rules in Table No. 8-5 against probable situations to determine the rates of ventilation at various depths (chamber pressures) that are likely to be needed. If the air supply is ample, determination of ventilation rates for a few depths (30, 60, 100, and 165 feet) may be sufficient, because the valve opening specified for a given rate of flow at one depth will provide at least that much at a deeper depth. It will be convenient to know the valve settings for rates like 30, 60, or 120 cubic feet per minute because these give a simple relationship between volume and time (60 cubic feet per minute = 1 cubic foot per second, etc.).

C. Determine the necessary valve settings for the selected flows and depths by using the chamber itself as a measuring vessel with the help of a stopwatch.

1. Calculate how long it would take to change the chamber pressure by 10 feet if the exhaust valve were letting air escape at the desired rate close to the depth in question. Use the following formula—

$$T = \frac{V \times 20}{R \times \frac{(P + 33)}{33}} \quad \text{(equation 8-1)}$$

where—

- T=time in seconds for chamber pressure to change 10 feet.
- V=internal volume of chamber (or of lock being used for test) in cubic feet.
- R=rate of ventilation desired, in cubic feet per minute as measured at chamber pressure.
- P=chamber pressure (gage) in feet of sea water.

Example—
How long will it take the pressure to drop from 170 to 160 feet in a 500-cubic-foot chamber if the exhaust valve is releasing 60 cubic feet of air per minute (as measured at chamber pressure of 165 feet)?

T=?
V=500 cubic feet
R=60 cubic feet per minute
P=165 feet

Substitute values in equation 8-1

$$T = \frac{500 \times 20}{60 \times \frac{(165+33)}{33}} = \frac{10{,}000}{60 \times 6} = 27.8 \text{ seconds}$$

2. Increase the chamber pressure (with no one inside) to 5 feet beyond the depth in question. Open the exhaust valve a certain amount and determine how long it takes to come up 10 feet. (For example, if checking for a depth of 165 feet, take chamber pressure to 170 feet and clock the time it takes to reach 160 feet.) Try opening the valve different amounts until you know what setting will give close to the desired time. Write down what the setting is. Calculate the times for other rates and depths and determine the settings for these times in the same way. Make a chart or table of the valve setting versus the ventilation rate and prepare a ventilation bill using this information and the ventilation rules.

Notes on Chamber Ventilation

A. The rules given in Table 8-5 are not intended to limit ventilation. If air is reasonably plentiful, more air than is specified should generally be used for the sake of comfort. This increase is desirable because it also further lowers the concentrations of carbon dioxide and oxygen.

B. There is seldom any danger of having too little oxygen in the chamber. Even with no ventilation and a high carbon dioxide level, the oxygen present would be ample for a long time.

C. These rules assume that circulation of air in the chamber during ventilation is reasonably good. If it is poor, the rules may be inadequate. Having the inlet near one end of the chamber and the outlet near the other end helps promote good ventilation.

D. Coming up to the next stop reduces the standard cubic feet of gas in the chamber and proportionally reduces the quantity (scfm) of air required for ventilation.

E. Continuous ventilation is by far the most efficient method of ventilation in terms of the amount of air required for ventilation. However, it has the disadvantage of exposing the men in the chamber to a constant source of noise. At the very high ventilation rates required for oxygen breathing, this noise can reach the ranges where hearing loss becomes a real hazard to the men in the chamber. If high sound levels do occur, especially during exceptionally high ventilation rates, the men in the chamber must wear ear protectors similar to those used in aviation on flight decks. Such ear protection is adequately afforded by a readily available stock item: Aural Protector, FSN-2RD-4241-759-3290-LF50. The only modification which these items require is a small hole drilled into the central cavity so that they do not produce an ear seal which could cause an ear squeeze.

F. Note that the size of the chamber does not influence the amount of air required for ventilation.

G. Note also that increasing depth increases the actual mass of air required for ventilation; but when the amount of air is expressed in volumes as measured at chamber pressure, increasing depth does not change the number of actual cubic feet required.

H. If high pressure air banks are being used for the chamber supply, pressure changes in the cylinders can be used to check the amount of ventilation being provided.

OXYGEN-ELIMINATION SYSTEM 8.4.3.5 A Navy approved oxygen elimination system is not presently available. Research is now underway to develop an adequate system, and when it receives Navy approval it will be detailed in a revision to this manual.

CHAMBER OPERATION 8.4.3.6 The recompression chamber should be operated in accordance with the instructions given in Table No's 8-4 and 8-5. No deviation from standard procedures should be attempted, except—

A. Under the direction of a diving medical officer.

B. In case of acute emergency or obvious necessity. During treatment the Rules for Recompression Treatment (Table No. 8-1) and the treatment tables should be carefully followed.

CHAMBER PRESSURE TEST 8.4.3.7 Every U.S.N. recompression chamber must undergo a pressure test upon its initial installation at a facility, whenever it is moved and re-installed and at five year intervals at a given location. Procedures for conducting this pressure test are given in Appendix L.

OPERATIONAL HAZARDS 8.5

In addition to environmental hazards, and those which directly grow out of diving itself, a diver will from time to time be exposed to man-made and natural hazards which are not unique to the diving environment. These include—

Electric Shock—
Rare underwater but will sometimes happen when using electric welding or power equipment.

Prevention—All such equipment should be in good repair, and inspected before diving. Correct operating procedures and safety rules should always be observed.

Treatment—Get the diver away from the source of current. Bring him to the surface and administer mouth-to-mouth resuscitation and closed-chest cardiac massage as necessary.

Explosions—
Which may be set off on purpose in demolition or clearance operations (by accident), or may be the result of enemy action.

Prevention—When working with or near explosives, follow the procedures given in NAVWEPS OP2081 and OP2212. Do not use welding or cutting torches in gas-filled compartments. Stay away from old or damaged munitions. Get out of the water when an explosion is imminent.

Treatment—Injury from an explosion will most likely be internal, caused as the shock wave differentially compresses the air spaces in the body (See Chapter Three). Get the victim out of the water, check for shock and internal bleeding.

Sonar—
Used by ships for object location and depth finding, is a high-intensity pulse of sound which can cause damage to the ears.

TABLE 8-4
RULES FOR CHAMBER OPERATION

ALWAYS

1. Take all precautions against fire.
2. Provide water and sand buckets.
3. Use fire retardant paint and materials in the chamber.
4. Ventilate the chamber according to specified rates and gas mixtures.
5. Assure proper decompression of all personnel entering the chamber.
6. Ensure that the chamber and its auxiliary equipment is in operational condition at all times.
7. Ensure that all personnel are trained in operation of equipment and are able to do any job required in treatment.
8. Prepare the chamber for immediate re-use following a treatment.

NEVER

1. Use oil on any oxygen fitting or piece of equipment.
2. Allow gas supply tanks to be depleted or reach low capacity.
3. Allow damage to door seals and dogs. Use minminimum force in "dogging down."
4. Leave doors dogged after pressurization.
5. Allow open flames, matches, cigarette lighters or pipes to be carried into the chamber.
6. Permit electrical appliances to be used in the chamber.

TABLE 8-5
CHAMBER OPERATING PROCEDURES

PRESSURIZATION

1. The diver and tender must enter the chamber together.
2. The diver should remain relaxed and sit in an uncramped position.
3. The tender closes and gently dogs the outer door.
4. The tender pressurizes the chamber, at a rate of 25 feet per minute, to the depth specified in the appropriate decompression or recompression table.
5. As soon as a seal is obtained about the door or upon reaching depth, the tender should release the dogs.

VENTILATION

1. When air or helium-oxygen mixture is breathed, provide 2 cubic feet per minute for each man at rest and 4 cubic feet per minute for each man who is not at rest, such as a tender actively taking care of a patient.
2. When oxygen is breathed, provide 12.5 acfm for a man at rest and 25 acfm for a man who is not at rest. When these ventilation rates are used, no additional ventilation is required for personnel breathing air. These ventilation rates apply only to the number of people breathing oxygen.
3. If ventilation must be interrupted for any reason, the time should not exceed 5 minutes in any 30 minute period. When ventilation is resumed, twice the volume of ventilation should be used for the time of interruption and then the basic ventilation rate should be used again.
4. The above rules apply to all chambers that do not have facilities to monitor the oxygen concentration in the chamber. Chambers that can monitor oxygen may use intermittent ventilation so that the oxygen concentration in the chamber does not exceed 22.5 percent. This ventilation also requires no additional ventilation for personnel breathing air.
5. If an oxygen elimination system is used for oxygen breathing, the ventilation rate required for air breathing may be used.

OXYGEN BREATHING

1. Use oxygen whenever permitted to do so by the tables unless the user is known to be intolerant of oxygen.
2. Adjust the breathing mask so that it seals tightly around the face.
3. Make sure that the tender knows the various symptoms of oxygen poisoning and how to react to each symptom. Remember the symptoms by V-E-N-T-I-D (Vision—Ears—Nausea—Twitching—Irritability—Dizziness).
4. Ventilate the chamber in accordance with the number of occupants breathing oxygen.
5. Be aware of increased fire hazard due to oxygen enriched environments and take all precautions to prevent a fire.

Prevention—Avoid diving in the vicinity of an operating sonar; approach no closer than 600 yards (if necessary), preferably 3,000 yards. SCUBA divers, wearing well-fitting wet suit hoods, can work within 100 yards of a sonar system. For short exposures, consult NAVSHIPS INST. 09940. 14 series.

Treatment—As for any ear damage.

Nuclear Radiation—

May be encountered as the result of accident, proximity to weapons or propulsion systems during salvage, weapons testing or, occasionally in a natural state. Exposure to radiation can result in serious damage to the body and its systems; levels of safe tolerance have been set and must not be exceeded. These levels may be found in the Radiological Control Manual, NAVSHIPS no. 389-0153 and Volume I of the Underwater Work Techniques Manual, NAVSHIPS No. 0994-007-8010.

Prevention—Avoid radioactive sites. If diving is necessary, provide appropriate protective clothing and post-dive cleansing.

Treatment—At the dive site, get the victim away from any sources of radiation and ensure that he has been thoroughly scrubbed and provided with fresh clothing. Obtain medical assistance.

Marine Life—
may be dangerous to man, either from direct physical attack or because of poisonous venoms. Some of these are extremely dangerous, and some are merely an uncomfortable annoyance. But the most important thing that a diver should know about marine life is that the dangers are largely overrated. In general, most underwater animals leave man alone. The diver's best protection against injury is knowledge. He should be able to identify the dangerous species which are likely to be found in his area of operations, and should know how to deal with each. Avoidance is the diver's best policy.

Several basic prevention rules are—

1. Be able to identify dangerous species—and know what it is about each that is dangerous.
2. Keep alert when diving or swimming. Watch where you put your feet and hands. Be particularly cautious when reaching into crannies or wrecks.
3. Keep movements smooth and steady. Thrashing attracts certain species. If you sight a shark or any large fish, try to remain motionless and quiet. Noise is more likely to attract than scare away.
4. Blood attracts sharks and other meat-eaters. If you cut yourself, get out of the water.
5. Handle any underwater animal with caution, whether it is alive or apparently dead. Many species have hidden barbs.
6. Big, "friendly" species can foul lines or cause other accidents—always be careful.
7. Watch out for entangling plants—especially some varieties of kelp, which can trap a diver and are very hard to cut.

Appendix I presents specific information about dangerous marine life, including identification factors, dangerous characteristics, most logical means to prevent injury, and methods of treatment.

Other Diving Emergencies 8.5.1 Most diving situations which can be considered to be emergencies have been mentioned in previous chapters. They will be briefly recounted in this section, with some elaboration when necessary for a clear understanding of the problem and the solution.

It cannot be too strongly emphasized that most serious problems are usually diver-caused, and the best solutions are all to be found in training and preparation. These will not eliminate all diving emergencies, but they will radically reduce the possibilities of accident and increase the probability of rapid and safe withdrawal from a developing hazard.

OMITTED DECOMPRESSION 8.5.1.1 Certain emergencies may interrupt or prevent specified decompression. Blow-up, exhausted air supply, bodily injury and the like constitute such emergencies. If the diver shows any symptoms of decompression sickness or gas embolism, immediate treatment using the appropriate oxygen or air recompression treatment table is essential. Even if the diver shows no symptoms of ill effects, omitted decompression must be made up in some manner to avert later difficulty.

Use of Surface Decompression Tables

The Surface Table Using Oxygen or the Surface Table Using Air may be used to make up omitted decompression only if the emergency surface interval occurs at such a time that water stops are not required or have already been completed.

Surface Decompression Tables Not Applicable

When the conditions which permit the use of the surface decompression tables are not fulfilled, the diver's decompression has been compromised. Special care must be taken to detect signs of decompression sickness, regardless of what action is initiated. The diver must be returned to pressure as soon as possible. The use of a recompression chamber is strongly preferred over in-water recompression.

When a Recompression Chamber is Available

Even if the diver shows no ill effects from his omitted decompression, he needs immediate recompression Take him to depth as appropriate for Recompression Treatment Table 1A or 5. If he shows no ill effects, decompress him in accordance with the Treatment Table. Consider any decompression sickness developing during or after this procedure as a recurrence.

When No Chamber is Available

Recompress the diver in the water following as nearly as possible Recompression Treatment Table 1A. Keep the diver at rest, provide a standby diver, and maintain good communication and depth control.

When this course of action is impossible, use the following procedure, which is based on the Standard

Air Decompression Table with 1 minute between stops—

- —Repeat any stops deeper than 40 feet.
- —At 40 feet, remain for one-fourth of the 10-foot stop time.
- —At 30 feet, remain for one-third of the 10-foot stop time.
- —At 20 feet, remain for one-half of the 10-foot stop time.
- —At 10 feet, remain for 1½ times the scheduled 10-foot stop time.

BLOW-UP 8.5.1.2 Blow-up occurs, with deep-sea gear, when the diver becomes over-buoyant and is carried upward in an uncontrolled ascent. As he rises, the expanding air in the suit progressively increases the rate of ascent, far beyond the point at which he can counteract the buoyancy by trying to dump air through his exhaust valve. Blow-up can lead to a number of serious problems, including gas embolism, decompression sickness, and physical injury from collision with surface objects. Additionally, should the diving suit rupture from the high internal pressure, the diver can fall back into the depths where he might be exposed to squeeze or drowning.

A diver should be particularly wary of the possibilities of blow-up when executing any maneuver which requires an increase in buoyancy—particularly if trying to free himself from a muddy bottom or similar situation where he is likely to suddenly break free. For a SCUBA diver, the condition can develop from underwater inflation of a life vest.

The possibility of blow-up is also high when engaging in underwater jetting or tunneling, where the silt or sand stirred up by the hose can clog the exhaust valve, resulting in a gradual, often unnoticed, buildup of air in the suit. It is good practice to work the chin button at regular intervals to ensure that the exhaust valve is clear and working properly.

Blow-up can also occur when a diver over-adjusts his air flow while trying to offset or avoid a squeeze. If a diver starts to fall underwater, facing the possibility of a serious squeeze, he may have to put himself into a blow-up condition on purpose. In general, blow-up poses the lesser immediate danger in such a case. If caught in a blow-up, the diver must exhale continuously to avoid gas embolism. When reaching the surface, he should vent enough air to prevent rupture of the suit while at the same time maintaining positive buoyancy. The tenders should take in the slack in the lines, get the diver out of the water and quickly examine him for signs of serious injury. If the dive did not require decompression, and if the diver appears to be uninjured, he should be closely watched and kept in the vicinity of the recompression chamber for several hours. If the diver did require decompression, or if any signs of decompression sickness or embolism appear, he should be put in the chamber at once.

FOULING AND ENTRAPMENT 8.5.1.3 Fouling and entrapment are more common with surface-supplied gear because of the ease with which the lines can become entangled. The diver must be particularly careful and watch not only his own lines but those of other divers as well.

While the surface-supplied diver may more easily become fouled, at the same time he will usually have an ample air supply while working to get free. The SCUBA diver may have no recourse but to ditch his gear and make a free ascent; if his body is trapped, he must face the possibility of running out of air before he can work free. This is another reason for always working with a buddy diver.

The first and most important action that a trapped diver can take is to **stop and think.** He must remain calm, analyze the situation, and carefully try to work out of it. Panic and over-exertion are the greatest dangers to the trapped diver, and if a simple effort will not resolve the situation, he should get help. Always keep in mind that a new umbilical can be provided to the surface-supplied diver, and that the SCUBA diver can be given a new apparatus or furnished with air by his buddy.

Once the diver has been freed and returns to the surface, he must be examined and treated with the following considerations in mind—

- —He will probably be over-tired and emotionally exhausted.
- —He may be suffering from, or approaching hypothermia.

—He may have some physical injury.
—A SCUBA diver may be suffering from asphyxia; additionally, if he has made a free ascent, he may have gas embolism.
—Prolonged decompression will most likely be required.

EQUIPMENT FAILURE 8.5.1.4 With good equipment, well maintained and thoroughly inspected and tested before each dive, actual operational failure will rarely be a problem. When a failure does occur, the correct procedure will depend upon the nature of the equipment and the nature of the dive. As with most emergencies, the training and experience of the diver and the diving team will be the most important factor in safely resolving the situation.

LOSS OF AIR SUPPLY 8.5.1.5 With surface supplied deep-sea gear, the diver will have sufficient air to breathe for about 7 minutes after a complete loss of air supply. He should close both the inlet, exhaust, and spitcock valves to conserve his air, and notify topside of his problem. If a cut hose is the cause of the trouble, the standby diver can bring down and attach another hose. Otherwise, the diver must get to the surface. Since he can no longer increase suit displacement, he must jettison weights to initiate a controlled blow-up.

A SCUBA diver without air or with a malfunctioning unit, should buddy breathe and ascend.

LOSS OF COMMUNICATIONS 8.5.1.6 Loss of contact, either visually (as between buddy divers) or over a diver-tender communication system, can be the first sign of a serious problem. Additionally, because coordination between divers, or between a diver and his tender, is interrupted, dangerous situations can rapidly develop.

If SCUBA divers lose sight of each other, one of three things could be involved—
—through inattention, they may have strayed away from each other.
—one diver had to surface and was unable to signal his departure.
—one diver is in trouble underwater.

The correct procedure—quickly determine that the buddy is not in trouble close at hand, but do not waste time in extended search. Get to the surface and notify the Diving Supervisor. It may well be that the other diver is already on the surface, or will be soon joining up as he follows the same procedure. Otherwise, the alerted Diving Supervisor will be able to take immediate action to muster all available assistance.

If telephone communications are lost with deep-sea gear, it may be that the system has failed—or it may be that the diver is in trouble.

The correct procedure—
—try line-pull signals at once; but keep in mind that, because of depth, current, bottom or work site conditions, they may not always work.
—check the rising bubbles of air; look for a cessation or marked diminution which could be signs of trouble.
—listen for sounds from the diving helmet. If no sounds are heard, the circuit is probably out of order. If the flow of bubbles seems normal, the diver may well be all right.
—if sounds are heard but the diver does not respond to signals, assume that he is in trouble.
—if another diver is on the bottom, have him investigate; or send down the standby diver.
—if there is doubt as to the diver's condition, don't hesitate to start bringing him toward the surface; the standby diver can meet him on the way, or communications may be restored.

LOST DIVER 8.5.1.7 In planning for an operation using SCUBA, "lost diver" procedures must be included and understood by all personnel.

The first stage of a lost diver condition is when communications have been lost. If the diver is not quickly located, or found at the surface (following correct lost communications procedure), the Diving Supervisor must immediately institute search procedures. At the same time, medical personnel should be notified and the recompression chamber alerted.

If the lost diver has become trapped or been injured, and if visibility is good, it should not be too hard to locate and assist him. If visibility is poor, the difficulty is greatly increased, as is the danger to the diver.

This, of course, is one reason for the requirement that SCUBA divers working under poor conditions must be equipped with a buddy line or a surface-tended life line.

A lost diver is often a disoriented diver who has lost his bearings and moved out of the operating area. Or he may be suffering from nitrogen narcosis or any other situation involving his breathing mixture, which can result in confusion, dizziness, anxiety or panic. Unknowingly, he could harm those attempting to rescue him. When located, his rescuer should approach him cautiously to prevent being harmed while his condition is briefly analyzed.

If the diver is unconscious when found, he must be immediately brought to the surface. If it is possible to provide him with a cleared air supply (such as a single hose demand SCUBA with a purge button) his rescuer should do so during the ascent.

EMERGENCY MEDICAL SUPPLIES 8.6

The number and variety of emergencies that can arise in diving require that a considerable number of items of medical equipment and supplies be available for prompt use by the medical officer or corpsman. What must be kept immediately at hand for first-aid and subsequent treatment depends somewhat on the availability of such items from the ship's regular sick-bay or from a dispensary or hospital close to a shore-based diving activity. The possible needs and means of filling them should be considered carefully and appropriate steps taken by the medical officer or corpsman responsible.

Every diving activity must maintain an emergency kit which can be available immediately at the scene of a diving accident or in the recompression chamber. The kit should be small enough to carry into the chamber immediately. Because many sterile items must be considered contaminated after exposure to increased atmospheric pressure, it is desirable to have a primary and a secondary emergency kit—

Kit No. 1—Primary Emergency Kit—
Diagnostic equipment needed routinely, and equipment most likely to be needed immediately.

Kit No. 2—Secondary Emergency Kit—
Equipment and medicines that might be needed, but that can be sent into the chamber if specifically required.

Suggested Contents Of Emergency Kits 8.6.1

Kit No.1—

Diagnostic equipment routinely useful—

- Flashlight
- Stethoscope
- Otoscope-ophthalmoscope
- Sphygmomanometer (aneroid type, never mercury)
- Reflex hammer
- Tuning fork
- Pin and brush for sensory testing
- Tongue depressors

Emergency treatment equipment and medications—

- Tongue depressors taped and padded as a bite pad for use in case of convulsions
- Oropharyngeal airway
- Rubber tubes equivalent to sizes 4 and 6 for temporary use in a tracheotomy, with a safety pin through that end to be kept outside the trachea.
- Sterile scalpel and blade assortment
- Sterile hemostats (two each)
- 5-cc syringe (two each) with needles
- Bandage scissors
- Epinephrine 1:1,000 aqueous for injection
- Sterile gauze pads
- Cotton balls
- Benzalkonium chloride

Miscellaneous—

- Adhesive tape
- Tourniquet

Kit No. 2—

Emergency equipment—

- Suture material, sterile
- Suture needles, assorted, sterile
- Sterile syringes
  5cc, 2 each
  10cc, 2 each
  30cc, 2 each
  Sterile needles, 16, 18, 20, and 22 gage, preferably disposable
- Three-way stopcocks, sterile, 2 each

- —Sterile thoracentesis needle, 16 gage, 4″ long
- —Sterile intracardiac needle
- —Sterile rubber tube for endotracheal suction (a soft-tip tube causes less damage to the trachea)
- —Endotracheal tubes, cuffed, selection
- —Laryngoscope

Emergency medications—

- —Intravenous fluids:
  - 5 percent dextrose in saline
  - 5 percent dextrose in water
  - Ringer's injection, lactated
- —Lidocaine
- —Cortico steroid for intravenous or intramuscular injection
- —Amobarbital sodium, injectable
- —Phenobarbital, injectable
- —Diazepam, injectable
- —Diphenylylhydantain sodium, injectable
- —Chloropromazine, injectable
- —Codeine, tablets
- —Aspirin
- —An injectable antihistamine
- —Sterile water for injection
- —Surgical soap

Miscellaneous—

- —Nasogastric tube
- —Asepto syringe
- —Sterile bladder catheterization tray (preferably disposable)
- —Intravenous infusion kits, sterile, disposable (two each)
- —Gauze roller bandage, 1″ and 2,″ sterile
- —Gauze sponges, 4″ by 4″, sterile
- —Band-Aids
- —Sterile gloves, surgical
- —Sterile towels
- —Splints
- —AMBU-type resuscitator
- —Eye patch

Use Of The Emergency Kit 8.6.2 The sterile supplies, if not adequately sealed against the increased atmospheric pressure, should be resterilized after each pressure exposure, or, if not exposed, at 6-month intervals.

Not all drug ampules will withstand pressure, and bottle stoppers may be pushed in. Bottles with stoppers may be vented with a needle during pressurization, and then discarded if not used.

Because the available facilities may differ on board ship, at land-based diving installations, and at diver-training or experimental units, the responsible medical officer or hospital man will have to modify the emergency kits to suit the local needs. Both kits should be taken to the recompression chamber or scene of the accident.

The emergency kit should be sealed in such a way that it can be opened readily when needed but will not be opened and plundered for no good cause. A broken seal will indicate that it has been opened. The kit should contain a list of contents, and each time it is opened (or at monthly intervals in any case), it should be checked for presence and condition of all items. Sterile supplies should be provided in duplicate so that one set can be autoclaved in the meantime.

Normally, use of the emergency kit should be restricted to the medical officer or a well-trained corpsman. Concise instructions for administration of each drug should be provided in the kit. In untrained hands, many of the items can be dangerous. Remember, that as in all types of treatment, YOUR FIRST DUTY IS NOT TO DO HARM. ▩

APPENDIX A

FORMULAS AND CONVERSION FACTORS

FORMULAS AND CONVERSION FACTORS

FORMULAS—

Listed below are formulas, and their respective units, which are commonly encountered in air diving operations.

Symbols and Notes

A	Area
C	Circumference
D	Depth of water
H	Height
L	Length
N	Number of divers
R	Radius
T	Tons
V	Volume
Dia.	Diameter
Dia.²	Diameter squared
Dia.³	Diameter cubed
π **(pi)**	3.1416
$\frac{1}{4}\pi$	.7854
$\frac{1}{6}\pi$	.5236
P.P.	Partial Pressure
psi	Pressure per square inch
psig	Gage pressure
psia	Absolute pressure
F.P.M.	Feet per minute
B.S.	Breaking strain of line or rope
S.W.	Safe working load of line or rope

Formula for Areas

The area of a square or rectangle—

$A = L \times W$

The area of a circle—

$A = .7854 \times Dia.^2$ or $A = \pi R^2$

Formulas for Volumes

The volume of a cube (compartment)—

$V = L \times W = H$

The volume of a sphere (balloon)—

$V = .5236 \times Dia.^3$

The volume of a cylinder (pontoon)—

$V = .7854 \times Dia.^2 \times L$

Lifting Capacity (In Pounds)

Fresh water $(V \times 62.4)$ = Weight of lifting unit

Salt water $(V \times 64)$ = Weight of lifting unit

Miscellaneous Formulas

Partial Pressure of a gas (in psi)—

$P.P. = [(D + 33) \times .455] \times \%$ of gas

$$P.P. = \left[\frac{D + 33}{33}\right] \times \% \text{ of gas, in ata.}$$

$P.P. = [D + 33] \times \%$ of gas, in fsw.

Time between stops in seconds—

$$T = \frac{(D_{left} - D_{arrived}) \times 60}{F.P.M.}$$

Emergency Hose Test $[(D \times .445) + 50] \times 2$

(Hold pressure for 10 minutes)

Formulas for Seamanship

1. Breaking strain of natural fiber line = $C^2 \times 900$ lbs.
2. Breaking strain of nylon wire = $C^2 \times 2{,}400$ lbs.
3. Breaking strain of wire = $C^2 \times 8{,}000$ lbs.

   Safe working load for 1-2-3 above—

   ¼ B.S. = S.W. for new line or wire

   ⅙ B.S. = S.W. for average line or wire

   ⅛ B.S. = S.W. for unfavorable conditions

Safe working load of a shackle =

$3 \times Dia.^2$ = S.W. in tons

Safe working load of a hook =

$\frac{2}{3} \times Dia.^2$ = S.W. in tons

CONVERSION TABLES—

Use of Tables—To use the conversion tables which follow, locate the row which has the number 1 given for the unit which is known. Move along that row to the column which lists the unit to be found. The number common to the known unit's row and the unknown unit's column is the multiplying conversion factor.

Example—Convert 34 FEET to METERS

1. FEET and METERS are units of length, so the LENGTH Table must be used.
2. In the FEET column, locate the number 1.
3. Follow that row to the METER column.

4. The number at the intersection is 0.3048. This means that 1 FOOT = 0.3048 METERS
5. Multiply the conversion factor (0.3048) by the number of known feet to obtain the equivalent number of meters.

$$34 \text{ FEET} \times \frac{0.3048 \text{ METERS}}{1 \text{ FOOT}} = 10.36 \text{ METERS}$$

ANSWER: 34 FEET = 10.36 METERS

Explanation of Exponents—

Positive exponents—To obtain total number, move the decimal point to the *right* a number of digits equal to the value of the exponent.
Examples—

$1.39 \times 10^3 = 1{,}390.$

$234.381 \times 10^5 = 23{,}438{,}100.$

Negative exponents—To obtain total number, move the decimal point to the *left* a number of digits equal to the value of the exponent.
Examples—

$23.71 \times 10^{-3} = 0.02371$

$1.394 \times 10^{-2} = 0.01394$

To Multiply—Carry the multiplication factor to the base 10 through to the final answer.
Examples—

To convert 937 BTU's to kilowatt-hours—

(937) (2.930×10^{-4} conversion factor)

$= 2745.41 \times 10^{-4}$

$= 0.275451$ kw-hr.

To convert 1.32 cubic yards to cubic centimeters—

(1.32) (7.646×10^5 conversion factor)

$= 10.09272 \times 10^5$

$= 1{,}009{,}272$ Cu cm

If both numbers have exponents, add the exponents algabraically.
Examples—

$(4.32 \times 10^4) \times (1.91 \times 10^5) = 8.251 \times 10^9$

$(4.32 \times 10^4) \times (1.91 \times 10^{-5}) = 8.251 \times 10^{-1}$

LENGTH EQUIVALENTS

Centimeters	Inches	Feet	Yards	Meters	Chains	Kilometers	Miles	Nautical Miles
1	0.3937	0.03281	0.01094	0.01	4.971×10^{-4}	10^{-5}	6.214×10^{-6}	5.396×10^{-6}
2.540	1	0.08333	0.02778	0.0254	1.263×10^{-3}	2.54×10^{-5}	1.578×10^{-5}	1.371×10^{-5}
30.48	12	1	0.3333	0.3048	1.515×10^{-2}	3.048×10^{-4}	1.894×10^{-4}	1.645×10^{-4}
91.44	36	3	1	0.9144	4.545×10^{-2}	9.144×10^{-4}	5.682×10^{-4}	4.935×10^{-4}
100	39.37	3.281	1.0936	1	4.971×10^{-2}	10^{-3}	6.214×10^{-4}	5.396×10^{-4}
2,012	792	66	22	20.12	1	2.012×10^{-2}	1.250×10^{-2}	1.086×10^{-2}
100,000	39,370	3,281	1,093.6	1,000	49.71	1	0.6214	0.5396
160,934	63,360	5,280	1,760	1,609	80	1.609	1	0.8683
185,325	72,962	6,080	2,026.5	1,853.3	92.11	1.853	1.1517	1

AREA EQUIVALENTS

Cubic Centimeters	Cubic Inches	Cubic Feet	Cubic Yards	Cubic Meters	Gallons	Liters	Pints (liq.)	Quarts (liq.)
1	.06102	3.531×10^{-5}	1.308×10^{-6}	10^{-6}	2.642×10^{-4}	10^{-3}	2.113×10^{-3}	1.057×10^{-3}
16.39	1	5.787×10^{-4}	2.143×10^{-5}	1.639×10^{-5}	4.329×10^{-3}	1.639×10^{-2}	3.463×10^{-2}	1.732×10^{-2}
2.832×10^{4}	1,728	1	3.704×10^{-2}	2.832×10^{-2}	7.481	28.32	59.84	29.92
7.646×10^{5}	46,656	27	1	0.7646	202.0	764.6	1,616	807.9
10^{6}	61,023	35.31	1.308	1	264.2	10^{3}	2,113	1,057
3,785	231	0.1337	4.951×10^{-3}	3.785×10^{-3}	1	3.785	8	4
10^{3}	61.02	3.531×10^{-2}	1.308×10^{-3}	10^{-3}	0.2642	1	2.113	1.057
473.2	28.87	1.671×10^{-2}	6.189×10^{-4}	4.732×10^{-4}	0.125	0.4732	1	0.500
946.4	57.75	3.342×10^{-2}	1.238×10^{-3}	9.464×10^{-4}	0.250	0.9463	2	1

VOLUME AND CAPACITY EQUIVALENTS

Kilograms	Grains	Ounces	Pounds	Tons (Short)	Tons (Long)	Tons (Metric)
1	15,432	35.27	2.205	1.102×10^{-3}	9.842×10^{-4}	10^{-3}
6.480×10^{-5}	1	2.286×10^{-3}	1.429×10^{-4}	7.143×10^{-8}	6.378×10^{-8}	6.480×10^{-8}
2.835×10^{-2}	437.5	1	6.25×10^{-2}	3.125×10^{-5}	2.790×10^{-5}	2.835×10^{-5}
0.4536	7000	16	1	5×10^{-4}	4.464×10^{-4}	4.536×10^{-4}
907.2	1.40×10^{7}	32,000	2000	1	0.8929	0.9072
1016	1.568×10^{7}	35,840	2240	1.12	1	1.016
1000	1.543×10^{7}	35,274	2205	1.102	0.9842	1

MASS EQUIVALENTS

Square Meters	Square Inches	Square Feet	Square Yards	Square Chains	Acres	Square Miles
1	1,550	10.76	1.196	2.471×10^{-3}	2.471×10^{-4}	3.861×10^{-7}
6.452×10^{-4}	1	6.944×10^{-3}	7.716×10^{-4}	1.594×10^{-6}	1.594×10^{-7}	2.491×10^{-10}
9.29×10^{-2}	144	1	0.1111	2.296×10^{-4}	2.296×10^{-5}	3.587×10^{-8}
0.8361	1296	9	1	2.066×10^{-3}	2.066×10^{-4}	3.228×10^{-7}
404.7	627,264	4,356	484	1	0.1	1.562×10^{-4}
4047	6,272,640	43,560	4,840	10	1	1.562×10^{-3}
2.59×10^{6}	3.346×10^{8}	2.788×10^{7}	3.0976×10^{6}	6400	640	1

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	3.281×10^{-2}	1.9685	2.237×10^{-2}	1.944×10^{-2}
100	1	60	3.6	3.281	196.85	2.237	1.944
1.667	1.667×10^{-2}	1	0.06	5.468×10^{-2}	3.281	3.728×10^{-2}	3.24×10^{-2}
27.78	0.2778	16.67	1	0.9113	54.68	0.6214	0.53996
30.48	0.3048	18.29	1.097	1	60	0.6818	0.59248
0.5080	5.080×10^{-3}	0.3048	1.829×10^{-2}	1.667×10^{-2}	1	1.136×10^{-2}	9.87×10^{-3}
44.70	0.4470	26.82	1.609	1.467	88	1	0.86898
51.44	0.5144	30.87	1.852	1.688	101.3	1.151	1

PRESSURE EQUIVALENTS

				Columns of Mercury @ 0°C		Columns of Water @ 15°C			
Atmospheres	Bars	Kilograms Per Square Centimeter	Pounds Per Square Inch	Meters	Inches	Meters (Fresh Water)	Inches (Fresh Water)	Feet (Fresh Water)	Feet (Sea Water) 1.02 Sp. Gr.
1	1.0133	1.0332	14.70	0.76	29.29	10.34	407.1	33.93	34.61
0.9869	1	1.0197	14.50	0.7501	29.53	10.21	401.8	33.49	34.16
0.9678	0.9807	1	14.22	0.7356	28.96	10.01	394.1	32.84	33.50
6.805×10^{-2}	6.895×10^{-2}	7.031×10^{-2}	1	5.171×10^{-2}	2.036	0.7037	27.70	2.309	2.355
1.316	1.3332	1.3595	19.34	1	39.37	13.61	535.7	44.64	45.53
3.342×10^{-2}	3.386×10^{-2}	3.453×10^{-2}	0.4912	2.54×10^{-2}	1	0.3456	13.61	1.134	1.157
9.67×10^{-2}	9.798×10^{-2}	9.991×10^{-2}	1.421	7.349×10^{-2}	2.893	1	39.37	3.281	3.347
2.456×10^{-3}	2.489×10^{-3}	2.538×10^{-3}	3.609×10^{-2}	1.867×10^{-3}	7.349×10^{-2}	2.54×10^{-2}	1	8.333×10^{-2}	8.500×10^{-2}
2.947×10^{-2}	2.986×10^{-2}	3.045×10^{-2}	0.4331	2.240×10^{-2}	0.8819	0.3048	12	1	1.02

ENERGY OR WORK EQUIVALENTS

Joules	Kilogram-Meters	Foot-Pounds	Kilowatt Hours	Horse Power Hours	Kilo-Calories	B.T.U.
1	0.10197	0.7376	2.778×10^{-7}	3.725×10^{-7}	2.388×10^{-4}	9.478×10^{-4}
9.8067	1	7.233	2.724×10^{-6}	3.653×10^{-6}	2.342×10^{-3}	9.295×10^{-3}
1.356	0.1383	1	3.766×10^{-7}	5.051×10^{-7}	3.238×10^{-4}	1.285×10^{-3}
3.6×10^{6}	3.671×10^{5}	2.655×10^{6}	1	1.341	859.9	3,412
2.685×10^{6}	2.738×10^{5}	1.98×10^{6}	0.7457	1	641.2	2,544
4,187	426.9	3,088	1.163×10^{-3}	1.560×10^{-3}	1	3.968
1,055	107.6	778.2	2.931×10^{-4}	3.93×10^{-4}	0.25200	1

POWER EQUIVALENTS

Horse Power	Kilo-Watts	Kg.-M. Per Second	Foot-Pounds Per Second	Kilocalories Per Second	B.T.U. Per Second
1	0.7457	76.04	550	0.1781	0.7068
1.341	1	102.0	737.6	0.2388	0.9478
0.01315	9.807x10^{-3}	1	7.233	2.342x10^{-3}	9.295x10^{-3}
1.82x10^{-3}	1.356x10^{-3}	0.1383	1	3.238x10^{-4}	1.285x10^{-3}
5.615	4.187	426.9	3,088	1	3.968
1.415	1.055	107.6	778.2	0.2520	1

TEMPERATURE EQUIVALENT

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
−100	−148.0	−60	−76.0	−20	−4.0	20	68.0	60	140.0	100	212.0	140	284.0
−98	−144.4	−58	−72.4	−18	−0.4	22	71.6	62	143.6	102	215.6	142	287.6
−96	−140.8	−56	−68.8	−16	3.2	24	75.2	64	147.2	104	219.2	144	291.2
−94	−137.2	−54	−65.2	−14	6.8	26	78.8	66	150.8	106	222.8	146	294.8
−92	−133.6	−52	−61.6	−12	10.4	28	82.4	68	154.4	108	226.4	148	298.4
−90	−130.0	−50	−58.0	−10	14.0	30	86.0	70	158.0	110	230.0	150	302.0
−88	−126.4	−48	−54.4	−8	17.6	32	89.6	72	161.6	112	233.6	152	305.6
−86	−122.8	−46	−50.8	−6	21.2	34	93.2	74	165.2	114	237.2	154	309.2
−84	−119.2	−44	−47.2	−4	24.8	36	96.8	76	168.8	116	240.8	156	312.8
−82	−115.6	−42	−43.6	−2	28.4	38	100.4	78	172.4	118	244.4	158	316.4
−80	−112.0	−40	−40.0	0	32	40	104.0	80	176.0	120	248.0	160	320.0
−78	−108.4	−38	−36.4	2	35.6	42	107.6	82	179.6	122	251.6	162	323.6
−76	−104.8	−36	−32.8	4	39.2	44	111.2	84	183.2	124	255.2	164	327.2
−74	−101.2	−34	−29.2	6	42.8	46	114.8	86	186.8	126	258.8	166	330.8
−72	−97.6	−32	−25.6	8	46.4	48	118.4	88	190.4	128	262.4	168	334.4
−70	−94.0	−30	−22.0	10	50.0	50	122.0	90	194.0	130	266.0	170	338.0
−68	−90.4	−28	−18.4	12	53.6	52	125.6	92	197.6	132	269.6	172	341.6
−66	−86.8	−26	−14.8	14	57.2	54	129.2	94	201.2	134	273.2	174	345.2
−64	−83.2	−24	−11.2	16	60.8	56	132.8	96	204.8	136	276.8	176	348.8
−62	−79.6	−22	−7.6	18	64.4	58	136.4	98	208.4	138	280.4	178	352.4

APPENDIX B

RECORD KEEPING AND REPORTING

The reports and records outlined in this section are designed to overcome certain inadequacies in the method of logging diving operations. On the assumption that the diver is the most immediately concerned with his own career, the responsibility for preparation of most of the records is placed on him. The responsibility for a high overall standard of completeness and accuracy rests progressively on the Diving Supervisor, the Diving Officer, and the Personnel and Commanding Officers.

DIVING RECORD SYSTEM

There are three objectives to be attained in the establishment of an adequate diving record system. These objectives are—

1. Establish a satisfactory operational record.
2. Provide data for analysis.
3. Establish a personal record.

The operational record may be described as a standardized record prepared in accordance with established military practice. Such a record is the normal minimum required when life is risked. It tends to ensure proper operational procedures and promotes safety and safe practices.

The second objective is to provide data for analysis. Without knowledge of the type and extent of diving being done in the Navy, it is impossible to estimate accurately the incidence of equipment failure and diving accidents, or to keep abreast of the needed procedures, training, and equipment to meet fleet diving requirements.

The establishment of a personal record in the third objective is an effort to promote esprit de corps and personal pride. By imposing a certain responsibility on the individual, he becomes more aware of the existence of the record and of the benefit of a good record.

The long, arduous, unrewarded dives amass an experience level that is, in itself, rewarding. The Diving Supervisor and Diving Officer are provided with an assessment factor to assist in the assignment of difficult diving jobs.

COMPONENTS OF THE SYSTEM

The components established to meet the objectives outlined above are:

1. Diving Log—Accident/Injury Report, OPNAV 9940/1; Figure B-1 shows the overlay and insert page.
2. Diver's Log Binder; Figure B-2
3. Diving Duty Summary Form; Figure B-2

DIVING LOG—ACCIDENT/INJURY REPORT—

Requirements—OPNAV Form 9940/1 must be filed for every dive (or hyperbaric exposure incident to diving) conducted under the auspices of the U. S. Navy in accordance with OPNAVINST 9940.2. Line 1 through 5 of the form must be filled out for every dive. Line 6 must be completed for each dive resulting in accidents or injuries.

Form Type—The Diving Log—Accident/Injury Report (OPNAV Form 9940/1) is a coded computer sheet which is inserted into a multi-leaf overlay (OPNAV Form 9940/1A). Instructions for writing the correct code numbers and letters on the report are printed on the leaves of the overlay.

Other Forms—OPNAV 9940/1 replaces Diving Log Sheet (NAVSHIPS Form 9940/1) and Report of Decompression Sickness and All Diving Accidents (NAVMED Form 6420/1). This form is used in lieu of the Accidental Injury/Death Report (OPNAV Form 5100/1) except in cases where a JAG Report is required. In this situation both forms OPNAV 9940/1 and OPNAV 5100/1 must be filed.

Disposition—Send completed form within 10 days to:
Naval Safety Center
Norfolk, Virginia

Instructions For Preparation of OPNAV 9940/1—

1. Each of the individual overlays contains instructions and coding symbols for each of the blocks on one line of the report form.
2. The following explanatory notes pertain to specific entry requirements—
   A. Activity dive set/group number; the sequential number of the particular dive, participated in by one or more divers, conducted by the reporting activity on

that calendar date; i.e., 08 would mean the eighth dive conducted by the activity on the reported date (not necessarily by the eighth diver).

B. Total number of divers in the group; numerical total from 01 to 99 divers participating in a particular activity dive.

C. The diver's number within the group; each diver in a group of divers participating in a particular activity dive is to be assigned a two-digit number from 01 to 99. The highest diver number must equal the total number of divers in the group, i.e. if 10 divers are participating in a dive, they will be numbered 01 through 10.

3. For each dive (subparagraph 2A above) in which no accident occurs, one report form with lines 1-5 (through decompression profile) is to be completed. Lines 1 and 2 of this report form will contain the date for diver number one of the group (defined in subparagraph 2C above). A separate report form containing lines 1 and 2 data only is to be completed for each of the other divers participating in the dive.
4. In the event that any item in lines 4 or 5 for a particular diver is different from the group, that item will be filled in on the report form for the particular diver.
5. In the event of a diving or diving related accident or injury, the entire report form (Lines 1-6) is to be completed for each affected diver.
6. Space at the top of each report form is provided for narrative remarks. In most cases, remarks will not be required, however, commands are encouraged to submit additional clarifying information, comments, or observations. A narrative is required in the event of accident or injury.

DIVER'S LOG BINDER

Issuance—A Diver's Log binder is issued to each graduate of the Naval School, Diving and Salvage. It is his personal record. The binder serves as a depository for his Diving Duty Summary forms.

Training activities other than the Naval School, Diving and Salvage, should present suitable binders to divers of any designation qualified by them.

Purpose—The binder and its contents are available to the Diving Supervisor to assist him in the detailing of divers. Each diver is responsible for maintaining his own records and for presenting his binder on each new assignment to diving duty. Each command may establish its own system for assisting the divers in keeping their records current and for providing proper stowage.

The Diver's Log is an official record and may be used for such purposes as determining the experience of divers and comparing the relative experience of several divers. Ultimately the log will be valuable when considering recommendation of a diver, first class, for advancement to master diver.

DIVING DUTY SUMMARY FORM

Issuance—Along with the log binder, each graduate of the Naval School, Diving and Salvage, is presented with two copies of a Diving Duty Summary Form. The initial entries recording qualification and the issuance of the log binder are completed and signed prior to presentation. The original is placed in the Diver's Log binder and the duplicate copy is placed in his service record.

Training activities other than the Naval School, Diving and Salvage, should prepare similar forms for presentation to divers of any designation qualified by them.

Purpose—This form, when properly filled out, represents a complete record of the diver's diving career. Each line entry represents a permanent assignment to diving duty. It includes all temporary additional duty assignments made within the permanent assignment period. One line may thus represent several years' service on board one command.

Responsibility—It is the diver's responsibility to ensure that both copies of the form are maintained current with each permanent assignment to diving duty or with each assignment to requalification diving. Just prior to detachment, he must sum up in his copy all the diving he has performed. It must then be turned in to the ship's office for transcription to the duplicate copy. Both copies must then be signed by the Commanding Officer or his authorized representative before the diver is transferred. The signature on the diver's copy signifies that the command approves his record and that it has been transcribed to the official copy.

Disposition—On failure to retain diving qualification, or on final separation from active duty, the form must be completed and the duplicate forwarded to the Officer in Charge, Navy Experimental Diving Unit, Washington Navy Yard, Washington, D. C. 20390.

Duplicate Diving Duty Summaries and Diver's Log binders may be requested from the Naval School, Diving and Salvage, when the original is verified lost or destroyed or when the individual re-enlists.

An individual who is retrained and redesignated at the Diving School after his previous qualification has lapsed is issued a new Diving Duty Summary. It must be the objective of all concerned to reduce to an absolute minimum the occasions requiring this retraining and redesignation.

Figure B-1 Overlay and Insert Page; Diving Log—Accident/Injury Report Form OPNAV 9940/1

Figure B-2 Diver's Log Binder and Diving Duty Summary Form

APPENDIX C

SEA STATE CHART

WIND AND SEA SCALE FOR FULLY ARISEN SEA

EA STATE CHART

IND AND SEA SCALE FOR FULLY ARISEN SEA

SEA-GENERAL			WIND			SEA						
EA TATE	DESCRIPTION	(BEAUFORT) WIND FORCE	DESCRIPTION	RANGE (KNOTS)	WIND VELOCITY (KNOTS)	WAVE HEIGHT FEET: AVERAGE	WAVE HEIGHT FEET: AVERAGE 1/10 HIGHEST	SIGNIFICANT RANGE OF PERIODS (SECONDS)	T (AVERAGE PERIOD)	I (AVERAGE WAVE LENGTH)	MINIMUM FETCH (NAUTICAL MILES)	MINIMUM DURATION (HOURS)
	Sea like a mirror	u	Calm	Less than 1	0	0	0	–	–	–	–	–
	Ripples with the appearance of scales are formed, but without foam crests.	1	Light Airs	1-3	2	0.05	0.10	up to 1.2 sec.	0.5	10 in.	5	18 mi
	Small wavelets, still short but more pronounced; crests have a glassy appearance, but do not break.	2	Light Breeze	4-6	5	0.18	0.37	0.4-2.8	1.4	6.7 ft.	8	39 mi
	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	3	Gentle Breeze	7-10	8.5	0.6	1.2	0.8-5.0	2.4	20	9.8	1.7 hr
					10	0.88	1.8	1.0-6.0	2.9	27	10	2.4
	Small waves, becoming larger; fairly frequent white horses.	4	Moderate Breeze	11-16	12	1.4	2.8	1.0-7.0	3.4	40	18	3.8
					13.5	1.8	3.7	1.4-7.6	3.9	52	24	4.8
					14	2.0	4.2	1.5-7.8	4.0	59	28	5.2
					16	2.9	5.8	2.0-8.8	4.6	71	40	6.6
	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray).	5	Fresh Breeze	17-21	18	3.8	7.8	2.5-10.0	5.1	90	55	8.3
					19	4.3	8.7	2.8-10.6	5.4	99	65	9.2
					20	5.0	10	3.0-11.1	5.7	111	75	10

Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray).	6	Strong Breeze	22-27	22	6.4	13	3.4-12.2	6.3	134	100	12
				24	7.9	16	3.7-13.5	6.8	160	130	14
				24.5	8.2	17	3.8-13.6	7.0	164	140	15
				26	9.6	20	4.0-14.5	7.4	188	180	17
Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen).	7	Moderate Gale	28-33	28	11	23	4.5-15.5	7.9	212	230	20
				30	14	28	4.7-16.7	8.6	250	280	23
				30.5	14	29	4.8-17.0	8.7	258	290	24
				32	16	33	5.0-17.5	9.1	285	340	27
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	19	38	5.5-18.5	9.7	322	420	30
				36	21	44	5.8-19.7	10.3	363	500	34
				37	23	46.7	6-20.5	10.5	376	530	37
				38	25	50	6.2-20.8	10.7	392	600	38
				40	28	58	6.5-21.7	11.4	444	710	42
High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong Gale	41-47	42	31	64	7-23	12.0	492	830	47
				44	36	73	7-24.2	12.5	534	960	52
				46	40	81	7-25	13.1	590	1110	57
Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility is affected.	10	Whole Gale	48-55	48	44	90	7.5-26	13.8	650	1250	63
				50	49	99	7.5-27	14.3	700	1420	69
				51.5	52	106	8-28.2	14.7	736	1560	73
				52	54	110	8-28.5	14.8	750	1610	75
				54	59	121	8-29.5	15.4	810	1800	81
Exceptionally high waves (Small and medium-sized ships might for a long time be lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	11	Storm	56-63	56	64	130	8.5-31	16.3	910	2100	88
				59.5	73	148	10-32	17.0	985	2500	101
Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	12	Hurricane	64-71	>64	>80	>164	10-(35)	(18)			

APPENDIX D

U S NAVY APPROVED DIVING EQUIPMENT

DEEP-SEA DIVING OUTFIT, AIR

ITEM	REQUIREMENT (as appropriate)	MANUFACTURER's Name	MANUFACTURER's Designation
Amplifier	FSN N -5830-184-1787	NA*	NA
Belt, Weight	FSN H -4220-223-6670	NA	NA
Cable, combination amplifier and lifeline			
200 feet	FSN G -5995-184-0096	NA	NA
600 feet	FSN G -5995-240-3225	NA	NA
Clamps, airhose	FSN C -4730-289-5912	NA	NA
Coupling, airhose, female	FSN C -4730-369-4589	NA	NA
Coupling, airhose, male	FSN C -4730-224-7325	NA	NA
Coupling, diving cable, telephone			
New style	FSN 5935-188-5844	NA	NA
Old style	FSN 5935-188-5834	NA	NA
Cuffs, diver's dress	FSN H -4220-223-6667	NA	NA
Cushion, diver's helmet	FSN H -4220-223-6659	NA	NA
Dress, diving			
Size #1, small	FSN H -4220-223-6660	NA	NA
Size #2, medium	FSN H -4220-223-6661	NA	NA
Size #3, large	FSN H -4220-223-6662	NA	NA
Faceplate, clear	FSN H -4220-351-2295	NA	NA
Faceplate, welding	FSN H -4220-351-2296	NA	NA
Gasket, faceplate	FSN Z -5330-197-8423	NA	NA
Gasket, helmet, leather	FSN C -4220-194-4834	NA	NA
Glass, helmet, face window	FSN H -4220-372-5460	NA	NA
Glass, helmet, side window	FSN H -4220-355-5459	NA	NA
Glass helmet, top window	FSN H -4220-355-5458	NA	NA
Glove, diver's			
(1) left hand	FSN C -4220-640-1529	NA	NA
(2) right hand	FSN H -4220-640-1530	NA	NA
Gloves, woolen, pr.	FSN D -8415-268-7900	NA	NA
Hose, assembly, air, high pressure	MIL-H-2815	NA	NA
3 feet	FSN C -4220-230-6531		
50 feet	FSN C -4220-230-6533		
200 feet (As available)	Same MILSPEC		

*(Not Applicable)

DEEP-SEA DIVING OUTFIT, AIR (cont'd.)

ITEM	REQUIREMENT (as appropriate)	MANUFACTURER's Name	MANUFACTURER's Designation
Helmet, deep sea diver, No. 1	FSN C -4220-223-6605	NA	NA
Jackbox, amplifier			
coilspring (new style)	FSN N -5935-243-5974	NA	NA
flatspring (old style)	FSN N -5935-184-1790	NA	NA
Lens, welding faceplate			
No. 4	FSN H -4220-369-4538	NA	NA
No. 6	FSN H -4220-369-4539	NA	NA
No. 8	FSN H -4220-369-4540	NA	NA
Manifold, air	FSN C -4220-142-1073	NA	NA
Nut, wing, breastplate, large	FSN H -4220-369-4541	NA	NA
Nut, wing, breastplate, small	FSN Z -5310-388-3439	NA	NA
Safety latch, helmet	FSN H -4220-355-5461	NA	NA
Shoes, divers, light (26 lbs)	FSN C -4220-278-9954	NA	NA
Shoes, divers, heavy (40 lbs)	FSN C -4220-223-6669	NA	NA
Springs, primary and secondary regulating escape valve	FSN H -4220-270-3087	NA	NA
Strap, cuff, divers dress with buckle	FSN H -4220-371-8068	NA	NA
Stud, breastplate, long	FSN H -4220-369-4544	NA	NA
Stud, breastplate, short	FSN H -4220-369-4545	NA	NA
Trousers, overalls	FSN C -4220-223-6666	NA	NA
Valve, air control angle	FSN C -4220-265-6953	NA	NA
Valve, regulating air escape (exhaust)	FSN C -4220-371-8070	NA	NA
Valve, air, nonreturn			
(1) New	FSN C -4220-604-6806	NA	NA
Washer, copper, for breastplate straps	FSN Z -5310-194-7252	NA	NA
Washer, airhose	FSN H -4220-250-2130	NA	NA
Washer, nonreturn valve seat	FSN Z -5330-239-1858	NA	NA
Washer, amplifier	FSN Z -5330-033-6613	NA	NA

DIVING OUTFIT, LIGHTWEIGHT (A SET, FSN 1H-4220-300-9929)

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's Name	MANUFACTURER's Designation
Belt, cartridge, unmounted	FSN D -8465-162-6150	NA	NA
Belt, leather	FSN C -4220-223-6671	NA	NA
Dress, swimmers, wet suit	(Open purchase)	NA	NA
Gloves, divers			
Left hand	FSN C -4220-640-1529	NA	NA
Right hand	FSN H -4220-640-1530	NA	NA
Gloves, woolen, pr.	FSN D -8415-268-7900	NA	NA
Harness, head, mask	FSN H -4220-369-4535	NA	NA
Hose, assembly 300 ft.	FSN C -4720-293-7997	NA	NA
Knife and sheath, divers	FSN C -4220-372-0665	NA	NA
Mask, divers	FSN C -4220-223-6665	NA	NA
Shoes, divers, light (26 lbs)	FSN C -4220-278-9954	NA	NA
Trousers, divers	FSN H -4220-223-6666	NA	NA
Tubing, elastic	FSN G -4720-221-2454	NA	NA
Valve, control, globe	FSN H -4220-369-4547	NA	NA
Valve, flapper, mask	FSN H -4220-369-4549	NA	NA
Valve, nonreturn	FSN C -4220-383-3825	NA	NA

SCUBA, OPEN-CIRCUIT DEMAND

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER'S Name	MANUFACTURER'S Designation
Attach board, Swimmers	Usually fabricated locally	NA	NA
Buoy marker inflatable, MK 1, Mod 0	MIL-B-24076, FSN S-2050-775-6556	NA	NA
Cartridge, CO_2 inflation	MIL-C-16385 FSN 9C-4220-287-3741	NA	NA
Compass, wrist Mark 1, Mod 1	FSN 1H-6605-079-0007	NA	NA
Compass, wrist,		Dacor SCUBAPRO	Model DCP 511, 519
Communications, wireless swimmer	Commercially available	HELLE Engr. Inc.	HE-10, HE-12
Cylinder, aluminum, SCUBA, (for use with single or double nonmagnetic harness.)	MIL-C-24316,90 ft^3, 3000 psi, part #0724-00 (as per Diving Manual) FSN 1H-4220-400-2944	NA	NA

SCUBA, OPEN-CIRCUIT DEMAND – cont'd.

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's Name	MANUFACTURER's Designation
Cylinder, nonmagnetic 30 grams for yoke-type, MK III, life preserver	FSN 1H-4220-965-0595	NA	NA
Cylinder, steel, SCUBA, (for use with single or double harness)	Manufactured as per MILSPEC, MIL-C-24447	U. S. Divers Co. Healthway Inc. Dacor Corp. W. J. Voight Sportsways Inc. SCUBAPRO	0637-00 0115 TG T-17 701-1 #160
Depth gage, diver's wrist MK 1, Mod 0	MIL-G-15214 FSN 2H-4220-639-8999	NA	NA
Depth Gage, magnetic commercial	MIL-G-15214 (less low magnetic effect requirements)	Dacor Corp. SCUBAPRO Sportsways Inc. U. S. Divers Co. VOIT White Stag	CDG 500, 505, 506, 507, 513, 516 1412 7022, 7205 DG 100 51230
Depth gage, hydrographic	MIL-C-24147, FSN H-4200-240-7150 (Naval Supply System)	NA	NA
Face Masks, magnetic	Tempered glass only, no other restriction	(Open purchase)	(Open purchase)
Harness, double for two aluminum SCUBA cylinders	Part #0808-00, Diving Manual (Naval Supply System)	NA	NA
Harness, single for single aluminum SCUBA cylinder	Specifically, shall be designed for use with one Navy aluminum cylinder	Dacor Corp.	NAV-SDP
Harness, double for two steel cylinders	Made commercially specifically for use with two 72 ft^3 steel cylinders with the positive screw-type bands	U.S. Divers Co. Healthways Inc. Dacor Corp. SCUBAPRO	0812 1445 Twin contour SCUBAPAK CDP-2 #182
Harness, single for single steel cylinder	Made commercially, specifically for a single 72 ft^3 steel cylinder with the positive screw type band	Healthways Inc. Dacor Corp. SCUBAPRO U. S. Divers Co.	1447 SCUBAPRO SDP #180 0819 AQUAPAC

SCUBA, OPEN-CIRCUIT DEMAND—cont'd.

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's Name	MANUFACTURER's Designation
Life preserver, UDT type	MIL-L-16383, FSN 2H-4220-276-8929	NA	NA
Life preserver, Yoke-type, Navy MK 3	MIL-L-24047 FSN 2H-4200-051-3078	NA	NA
Lights, Divers	Commercially available	Dacor Corp. Giddings/Felgen	PUL-2 Sealight 7 and 12
Manifold, single magnetic with "J" valve	"J" type only—no other	U. S. Divers Co. Dacor Corp. W. J. Voight Sportsways Inc. SCUBAPRO	0525 JV V1J SJ 704 A #152
Manifold, double, magnetic with "J" valve	"J" valve only—no other. The Navy nonmagnetic manifold shall not be used.	U. S. Divers Co. Dacor Corp. W. J. Voight Sportsways Inc.	0518 TRG-2 V2J SJ2 704 C
Pressure Gage, submersible	Commercially available	Dacor Corp. Nemrod SCUBAPRO Sportsways, Inc. U. S. Divers Co. VOIT White Stag	DPG 99-6919 132 1401-S, 1401 7025 DS109 51151
Regulator, demand double hose	MIL-R-19558 FSN 1H-4220-912-4237	U. S. Divers Co. Royal Aquamaster Dacor Corp.	Aquamaster (USD PN1010) C-3
Regulator, demand single hose	MIL-D-22962 and MIL-R-24169	Scott Aviation Dacor Corp. SCUBAPRO U. S. Divers Co. VOIT	#800600 Olympic models 100, 200 & 400 MK 1, MK 5, MK 7 Military model CONSHELF VI CONSHELF XII CALYPSO IV CALYPSO J AQUARIUS R-12-J, MR-12, R-12
Strap, wrist watch	MIL-S-46383, FSN 1H-6645-679-0614	NA	NA
Surfboard, paddle board plastic	MIL-S-18485	NA	NA

SCUBA, OPEN-CIRCUIT DEMAND—cont'd.

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER'S Name	MANUFACTURER'S Designation
Swim fins	No restrictions	(Open purchase)	(Open purchase)
Watches, wrist submersible	Wrist watch strap, FSN 1H-6645-679-0614, shall be used with this watch	Benrus Watch Co. Rte. #7, Ridgefield, Conn. 06877	Noblesse SCUBA
		Amer. ROLEX Watch Corp.	Seadweller 1665-S Submariner 7016 Submariner Date 1680-S Tudor Submariner 7021
		SCUBAPRO AQUASTAR	Benthos 500
		U. S. Divers Co.	Shark Hunter 7269 Sea Rambler 7270
		Zodiac	Super Sea Wolf #1796
Wet suits, including bottles, gloves, hoods, etc.	No restrictions	(Open purchase)	(Open purchase)

OTHER DIVING EQUIPMENT

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's Name	MANUFACTURER's Designation
Inhalator, divers HeO_2 decompression	FSN G-4220-240-7150	NA	NA
Shoes, swim coral	FSN 8430-551-2527	NA	NA
Sonar, communication set, AN/PQC-1A	FSN F-5845-884-2113	NA	NA
SDV, MK3, Mod 0 2-man, (Seahorse)	NAVSHIPS special material	NA	NA
SDV, MK IV, Mod 0 4-man (TRASS III)	NAVSHIPS special material	NA	NA
SDV, MK VII, Mod 0 4-man, (Convair 14)	NAVSHIPS special material	NA	NA
Recompression chambers, double lock, steel, 100 psi	FSN S-4220-368-3345	NA	NA
Recompression chambers, single lock, steel, 100 psi	FSN S-4220-368-3346	NA	NA

OTHER DIVING EQUIPMENT—cont'd.

ITEM	REQUIREMENT (As Appropriate)	MANUFACTURER's Name	MANUFACTURER's Designation
Recompression chambers, double lock, aluminum 100 psi	FSN S-4220-540-2785	NA	NA
SCUBA, Aquanaut equipment, MK11, Mod 0	Special material, available only as directed by SUPDIVE	NA	NA
Diver's Mask USN MK I	Special material, available only as directed by SUPDIVE	NA	NA
UNISUIT	Special material, available only as directed by SUPDIVE	NA	NA

APPENDIX E

SELECTION, QUALIFICATION AND TRAINING OF PERSONNEL

GENERAL E.1

In the selection of personnel for diving training, the commanding officers and examining boards shall be guided strictly by the Bureau of Naval Personnel Manual, the Manual of the Medical Department, BUPERS Formal Schools Catalog, NAVPERS 91767-A1, and other current instructions.

Physical and Psychological Commands must insure that applicants for all types of diving duty are properly screened prior to being ordered to diving instruction. To effect such screening, order applicants to the nearest activity having facilities to conduct the following:

A PHYSICAL EXAMINATION—This must be administered by a medical officer in accordance with the Manual of the Medical Department Article 15-30 to determine fitness for diving training.

B RECOMPRESSION CHAMBER PRESSURE TEST—Candidates shall be subjected to a pressure of 50 psig.

C OXYGEN TOLERANCE TEST—At the time of his initial examination, each candidate for diving training must demonstrate his ability to tolerate breathing pure oxygen at a simulated depth of 60 feet for 30 minutes at rest. The purpose of this test is to eliminate from diving duty those individuals who are susceptible to oxygen intoxication to a degree that may be hazardous to themselves and others. To maintain uniform standards, certain procedures must be followed. The oxygen must be supplied through a demand valve. Oxygen masks and systems employing a rebreathing bag must not be used. If a man has a convulsion or demonstrates definite preconvulsive signs (i.e., twitching of lips or limbs) during the test, he has failed. The test must not be repeated. If during the test the candidate complains of symptoms such as nausea, tingling sensations, dizziness, or others, the test may be terminated and repeated at a later date at the discretion of the medical officer.

D A TEST DIVE IN A DIVING SUIT UNDER THE GUIDANCE OF A QUALIFIED OFFICER—In this connection, it has been repeatedly demonstrated that a man showing any reluctance or timidity in making his initial dive seldom becomes an acceptable diver.

E INTERVIEW BY A QUALIFIED DIVING OFFICER TO ASCERTAIN, INSOFAR AS POSSIBLE, THE ATTITUDE AND MOTIVATION OF THE APPLICANT—Because of the nature of the duties and responsibilities of each officer and man engaged in diving, the psychological fitness of each officer and man for diving training should be carefully appraised. All diving candidates must be volunteers. The individual should have arrived at his decision for diving after mature deliberation, and should be motivated by a real desire for this duty. Emotional maturity, stability, dependability, and at least normal intelligence are necessary. Psychiatric conditions or personality traits that might prevent satisfactory adjustment to diving duty are disqualifying factors.

NOTE

Section E.2 of this appendix is taken from the Manual of the Medical Department, article 15-30, and covers the physical and medical qualifications for diving. Section E.3 of this appendix is taken from the Bureau of Naval Personnel Manual, article 1410380, and outlines the requirements which must be met by the applicant to become a diver and to retain that designation.

DIVING DUTY, MEDICAL E.2

1—All accepted candidates for duty that involves diving or underwater swimming shall conform to the following standards—

A HISTORY OF DISEASE—Any of the following shall be disqualifying—

1 Tuberculosis, asthma, chronic pulmonary disease.
2 Chronic or recurrent sinusitis, otitis media, otitis externa.
3 Chronic or recurrent orthopedic pathology.
4 Chronic or recurrent gastrointestinal disorder.
5 Chronic alcoholism.
6 No candidate shall be accepted with a history of syphilis, unless there has

been adequate treatment and no signs of activity or organic involvement are discovered.

B AGE—Candidates beyond the age of 30 years shall not be considered for initial training in diving, the most favorable age being from 20 to 30. All divers upon reaching the age of 40 shall be examined in accordance with subarticle P.4. For officers undergoing training in deep-sea diving for the specific purpose of becoming diving supervisors or salvage officers, the upper age limit shall be 39 years. In cases where the candidate's age is 40 or more, the provisions of subarticle P.4 below shall apply.

C WEIGHT—Diving candidates should be rugged individuals without tendency toward obesity. Fatty tissue absorbes about five times the volume of nitrogen as does lean tissue. Because of the low circulatory rate of fatty tissue, nitrogen is eliminated very slowly, thus increasing the incidence of bends. It is considered in general that candidates should present no greater than 10 percent variation from standard age-height-weight tables. Consideration will be given, however, to applicants whose overweight is considered to be due to heavy bone and muscular structure.

D VISION—A minimum of 20/30 vision bilateral, corrected to 20/20, shall be required. This requirement is not made for underwater work but for the retention of relatively high physical standards for hazardous work in connection with diving and salvage operations. Ophthalmoscopic examination shall be normal.

E COLOR VISION—Normal color perception is required of all candidates.

F TEETH—A complete dental examination shall be conducted by a dental officer, if available. If a dental officer is not available, the examination shall be conducted by a medical officer. Acute infections or disease of the soft tissues of the oral cavity are disqualifying until remedial treatment is completed. Advanced oral diseases and generally unserviceable teeth shall be cause for rejection. Applicants with moderate malocclusion, or extensive restorations and replacements by bridges or dentures, may be accepted if such do not interfere with effective use of self-contained underwater breathing apparatus (scuba).

G EARS—Acute or chronic disease of the auditory canal, membrana tympani, middle or internal ear shall be disqualifying. Perforation or marked scarring and/or thickening of the drum shall be disqualifying. The eustachian tubes must be freely patent for equalization of pressure changes. Hearing of each ear shall be normal.

H NOSE AND THROAT—Obstruction to breathing or chronic hypertrophic or atrophic rhinitis shall disqualify. Septal deviation is not disqualifying in the presence of adequate ventilation. Chronically diseased tonsils shall be disqualifying pending tonsillectomy. Presence or history of chronic or recurrent sinusitis is cause for rejection.

I RESPIRATORY SYSTEM—The lungs shall be normal as determined by physical examination and 14 by 17-inch chest X-ray.

J CARDIOVASCULAR SYSTEM—The cardiovascular system shall be without significant abnormality in all respects as determined by physical examination and tests. The blood pressure shall not exceed 145 mm systolic, or 90 mm diastolic. In cases of apparent hypertension, repeated daily blood-pressure determinations should be made before decision. It should be kept in mind that a valuable indication of undesirable excitable temperament is often revealed by vasomotor manifestations (see N below). Persistent tachycardia and arrhythmia except of sinus type, evidence of arteriosclerosis (an ophthalmoscopic examination of the retinal vessels shall be included in the examination), varicose veins, marked or symptomatic hemorrhoids shall be disqualifying.

K GASTROINTESTINAL SYSTEM—Candidates subject to gastrointestinal disease shall be disqualified.

L GENITOURINARY SYSTEM—The following shall be disqualifying—

1 Chronic or recurrent genitourinary disease or complaints (normal urinalysis required).

2 Active venereal disease or repeated venereal infection.

3 History of clinical or serological evidence of active or latent syphilis within the past five years, or of cardiovascular or central nervous system involvement at any time. An applicant who has had syphilis more than 5 years before must have negative blood and spinal fluid serology.

M SKIN—There shall be no active acute or chronic disease of the skin on the basis of infectiveness and/or offensiveness in close working conditions and interchange of diving apparel.

N TEMPERAMENT—The special nature of diving duties requires a careful appraisal of the candidate's emotional, temperamental, and intellectual fitness. Past or recurrent symptoms of neuropsychiatric disorder or organic disease to the nervous system shall be disqualifying. No individual with a history of any form of epilepsy, head injury with sequelae, or personality disorder shall be accepted. Neurotic trends, emotional immaturity or instability and asocial traits, if of sufficient degree to militate against satisfactory adjustment, shall be disqualifying. Stammering or other speech impediment which might become manifest under excitement is disqualifying. Intelligence must be at least normal.

O ABILITY TO EQUALIZE PRESSURE—All candidates shall be subjected in a recompression chamber to a pressure of 50 psig to determine their ability to clear their ears effectively and otherwise to withstand the effects of pressure. Due consideration must be given to the presence of an upper respiratory infection which temporarily may impair the ability to equalize pressure because of congestion of the eustachian tube.

P SUSCEPTIBILITY TO OXYGEN—Individual susceptibility to oxygen shall be tested by determining the candidate's ability to breathe oxygen without untoward effects at a pressure of 60 feet (27 psig) for a period of 30 minutes.

2—Reexamination of all divers shall be conducted in January of each year in accordance with standards set forth above. Pressure and oxygen-tolerance tests may be omitted from the annual physical examination for those divers who have maintained their diving qualifications in accordance with current BUPERS directives. A notation of physical examination shall be placed in NAVMED 1346 and Standard Form 600 of the Health Record.

3—Divers shall ordinarily be examined prior to each unusually hazardous dive. Examination of divers shall be made at the discretion of the medical officer prior to the start of extensive rescue, salvage, or diver-training operations. The medical officer should make observations, by personal interview if possible, of all divers prior to their initial dive each day.

4—Qualified divers who desire to continue in that specialty and are about to reach the age of 40 shall be examined by a board of medical officers appointed by the senior officer present. At least one member of the board shall be qualified as a deep-sea diver or in submarine medicine. The report of the examination on Standard Form 88 with the recommendation of the board as to whether the individual is or is not physically qualified to continue as a diver shall be forwarded to the Bureau of Medicine and Surgery for final decision and in time to reach BUMED before the man attains the age of 40. A certain latitude may be allowed for a diver of long experience and a high degree of efficiency in diving.

He must be free from any disease of the cardiovascular, respiratory, genitourinary, and gastrointestinal systems, and of the ear. His ability to equalize air pressure must be maintained. A moderate degree of overweight may be disregarded if the diver is otherwise vigorous and active.

QUALIFICATIONS FOR DIVERS E.3

1—Qualified divers are divided into six classes according to their degree of qualification as follows—

- —Master Divers (5341).
- —Saturation Diver (53ll).
- —Divers First Class (5342).
- —Medical Deep-Sea Diving Technician (8493).
- —Salvage Divers (mobilization only).
- —Divers Second Class (5343).
- —Scuba Divers (5345).

NOTE

When a man has been trained and qualified as a diver, an entry shall be made on page 13 of his service record as follows—

DATE: Qualified as ________________ to
(class diver)
a depth of _______ feet. Qualification lapse date ________________.
Authorized assignment to NEC _____ ______________ Diving Billets (see OPNAV Form 1000/2) and entitled to receive appropriate pay when performing the duties of the billet.
Assignment of NEC _____________ recommended to BUPERS. AUTH: Article 1410380 (1) BUPERS Manual.

Signature _________________

2—Navy Enlisted Classifications which include a degree of diving qualification, collateral to basic classification, are as follows—

- Underwater Demolition Team Swimmer (5321).
- Underwater Demolition Team Swimmer/Explosive Ordnance Disposal Technician (5322).
- Combatant Swimmer (SEAL Team) (5326).
- Combatant Swimmer (SEAL Team/Explosive Ordnance Disposal Technician) (5327).
- Explosive Ordnance Disposal Technician (5332).
- Underwater Photographer (8136).
- Hospital Corpsman, Special Operations Technician (8492).

NOTE

When a man has been trained and qualified in one of the above categories, an entry shall be made on page 13 of his service record as follows:

DATE: Qualified as ______________ to
depth of _______ feet. Qualification lapse date _______. Authorized assignment to NEC ________________ Billet (in OPNAV Form 1000/2) and entitled to receive appropriate pay when performing the duties of the billet. Assignment of NEC _________ ____________ recommended to BUPERS. AUTH: Article 1410380(2) BUPERS MANUAL.

Signature ___________________________

3—Classification and designation

A After a BUPERS Report 1080-14 listing the appropriate NEC has been received and the page 4 service record entry made assigning the appropriate NEC, this code will not be removed because the man's qualification as a diver lapses, but will be retained as long as he is capable of being requalified as a diver. Personnel no longer volunteering or capable of requalifying for diving duties shall be reported to the Chief of Naval Personnel in order that their diver NEC's can be revoked.

B The enlisted designator shall be placed immediately after the man's rating abbreviation in parentheses and shall appear with his rating abbreviation on all service-record pages and on all correspondence pertaining to him thereafter as long as he remains a qualified diver. In the case of a diver's failure to requalify by the end of his qualification period, the DV designator must be removed on the date following the last date of the qualification period. The DV designator may, however, be restored by the commanding officer upon completion of the necessary requalification dives not later than 1 year after lapse of qualification. Should qualification lapse continuously for a period of 1 year, the individual must be retrained in accordance with paragraph 6 following. All actions which result in the assignment or removal of the enlisted designator (DV) shall be reported immediately to the cognizant PAMI by an appropriate diary entry.

4—Training and selection

A In the training and selection of men as divers, commanding officers and examining boards shall be guided strictly by the Bureau of Naval Personnel Manual, the Manual of the Medical Department, the Bureau of Naval Personnel Formal Schools Catalog NAVPERS 91769 (current series), and other current instructions.

B An officer will be assigned responsibility for any and all diving. That officer will study all diving publications available and will make every effort to assure himself that all diving is conducted in accordance with good diving practice. He will particularly insure that the man in charge of the actual diving operations is a diver whose competency, responsibility, and reliability are commensurate with the particular operation.

5—Physical Requirements

No man shall be allowed to dive unless he has been found physically qualified by examination in accordance with article 15-30 of the Manual of the Medical Department within the preceding 12 months, or following any intervening illness or accident considered likely to affect physical qualifications for diving.

6—Tenure, Qualification, and Requalification

Periodic qualification of all divers is necessary to insure continuous proficiency and maximum safety. Divers will be qualified for 6-month periods. An entry will be made in the service record to show the period of a diver's qualification. When dives are conducted in accordance with the requirements listed below within the period of qualification, a diver will be considered qualified for another 6-month period, beginning on the date his qualification would have elapsed. If dives are conducted in accordance with the requirements listed below within 1 year of the date on which qualification lapsed, the diver will be considered requalified, and an entry to that effect will be made in the service record. If a diver's qualification has lapsed continuously for more than 1 year, he will be retrained and redesignated in accordance with paragraphs 8 through 13 herein as applicable, but only after his permanent interest in diving and his sincere desire for redesignation are established. Entitlement to special pay for diving duty depends upon the maintenance of qualification by actual performance of dives according to the tables listed below. Accordingly, no extensions of diver qualifications are authorized except by the actual performance of prescribed qualification dives. Four dives in accordance with the tables listed below are required to maintain diver qualifications, except that UDT swimmers, EOD technicians, underwater photographers, hospital corpsmen special-operations technicians, and scuba divers are required to perform a combination of dives and swims using scuba equipment.

A Master divers, divers first class, and medical deep-sea diving technicians, basic—Four dives are required under any of the depth-time requirements below—

Depth of water, feet	Minimum bottom time, minutes
100 to 150	45
150 to 170	30
170 to 200	15
200 plus	10

A minimum of two of the required four dives shall be made using helium-oxygen as a breathing medium when attached to helium-oxygen equipped vessels or activities.

B UDT/SEAL Swimmers—Candidates for this classification must execute the following—

	Minimum depth or distance	Minimum bottom time, minutes
Day—		
2 dives	120 feet	10
2 scuba swims on compass course.	1-1,000 yards— 1-1,500 yards—	
Night—		
2 scuba swims on compass course.	1-1,000 yards— 1-1,500 yards—	

C EOD Technicians—The following are required to be qualified in this category—

Dives—
Two dives, of 120 feet for 10 minutes.
Two dives, of 30 to 130 feet (EOD/MWD problems in connection with the location of, and disposal or rendering safe of ordnance).

Scuba Swims—
Two, of 500 yards each.

D Salvage divers and divers second class, basic —Four dives (search or salvage work problems) are required, each being at a depth between 30 and 150 feet, and lasting a minimum of 45 minutes.

E Scuba divers, underwater photographers, and hospital corpsmen special operations technicians—Requirements for these qualifications are—

Dives—
One dive of 50 to 70 feet for 10 minutes.
One dive of 70 to 130 feet for 5 minutes.

Scuba swims—
Two scuba swims of 500 yards each.

F Master divers, divers first class, and medical deep-sea diving technicians may take requalifying dives in accordance with subparagraph (D) above when permanently attached to activities that are part of the shore establishment when available water depths or equipment limitations preclude requalification in accordance with subparagraph (A) above. This provision does not apply to activites having wet pressure tanks installed. Other classes of divers in the above category may make requalifying dives in accordance with subparagraph (D) above; but must in addition complete those scuba swims specified in subparagraph (B), (C), or (E) above as applicable.

G Dives and swims made during regular diving operations will count for retaining diver qualification, provided they meet the requirements of subparagraphs (A) through (E) above. Minimum depths and duration of qualification and requalification dives outlined therein are not intended to prescribe operational diving limitations.

H Commands are expected to insure that divers maintain proficiency in the use of all types of diving equipment for which qualified, insofar as the individual activity's authorized equipment will permit. Training and requalification diving should be planned to include salvage, search and repair exercises utilizing deep-sea, lightweight, scuba, and helium-oxygen equipment if so outfitted.

I All divers should receive free-ascent training at one of the submarine-escape training tanks when possible. Under no circumstances will this training be conducted at other activities unless a recompression chamber is readily available and the training is under the direct supervision of a diving officer and submarine medical officer assisted by well-qualified instructors in free-ascent techniques.

7—Revocation of Designation
Commanding officers may recommend to the Chief of Naval Personnel the revocation of the designation of any class of diver with reasons therefor. Whenever a designation is revoked, an entry will be made on the administrative-remarks page of the service record, showing date of revocation and reasons therefor, and reported as a miscellaneous change to the cognizant PAMI.

8—Distinguishing Mark
An enlisted man who qualifies as a diver will be authorized to wear a distinguishing mark as prescribed by the U. S. Navy Uniform Regulations, 1969-Authorization to wear the distinguishing mark will continue throughout the tenure of qualification. Master divers, who through no fault of their own, are physically disqualified from continuance in diving, may continue to wear the master diver distinguishing mark.

9—Requirements for Master Divers (effective 1 February 1962)

A Designation—Master divers are the most competent divers first class who have been recommended by their commanding officer and approved by the Chief of Naval Personnel for designation as master diver to fill an authorized billet at a diving activity. Commanding officers of diving-type activities may recommend by letter to the Chief of Naval Personnel any diver first class for designation as master diver who fulfills the qualification requirements listed below. No waiver of these requirements is authorized except that the Chief of Naval Personnel will consider, on an individual basis when so recommended by the commanding officer, the waiver of one-type vessel service requirement in the case of individuals whose performance is of such excellence as to warrant special consideration. The letter of recommendation will note the fulfillment of each requirement and will contain a statement of duties performed as a diver.

B Eligibility requirements—The candidate must—

1 Be a chief petty officer, pay grade E-7 or above other than hospital corpsman, a minimum of 1 year.

2 Have served a minimum of 2 years with the designation and qualification of diver first class.

3 Have served as a qualified diver first class a minimum of 12 months aboard a helium-oxygen-equipped diving vessel, and as a qualified salvage diver, or above, a minimum of 12 months aboard an ARS or ARSD-type diving vessel.

4 Have averaged during the preceding year at least 3.5 in each of the following with no individual mark less than 3.2: professional performance; leadership; and supervisory ability.

5 Be a designated diver first class.

6 Be a graduate of the master diver qualification course conducted at Naval School, Diving and Salvage, Washington, D. C.

C Qualification factors—The qualification factors are as follows—

1 Demonstrate ability to take charge of all phases of helium-oxygen diving.

2 Demonstrate ability to plan and take charge of all diving operations.

3 Demonstrate ability to take charge of operation and maintenance of a submarine-rescue chamber.

4 Demonstrate knowledge of all Navy-procured types of self-contained underwater breathing equipment, including their advantages and limitations.

5 Know the methods and materials used in unbeaching ships on strand under various conditions of beach, sea, and water, and refloat sunken vessels.

6 Demonstrate knowledge of the types of compressors used habitually in diving operations, including the various filtering methods and the necessary precautions to observe.

7 Understand the principles of the general gas law and its derivatives (Boyle's and Charles' laws).

8 Understand the principles of Dalton's law of partial pressures and Henry's law of fluid saturation.

9 Understand the theory of inert-gas saturation and desaturation of body fluids and tissues.

10 Understand the principles involved in the computation of various decompression tables.

11 Recognize the different forms of decompression sickness and know the treatment required.

12 Understand the effect upon the respiratory system of such poisonous gases as may be encountered in diving, and know the treatment required.

13 Know the name and use of equipment required for safe diving operations.

14 Know the causes, symptoms, and treatment of, and preventive measures for, all types of diving accidents.

15 Have a comprehensive knowledge of the scope, content, and application of Navy publications and instructions pertaining to diving, such as the Diving Manual (NAVSHIPS 0994-001-9010) and applicable sections of the Naval Ship Systems Command Technical Manual, Manual of the Medical Department, and Bureau of Naval Personnel Manual.

10— Requirements for Saturation Divers

The Saturation Diver NEC 5311 assignment is contingent upon completion of the specialized Saturation training program and formal recommendation by the Saturation Training Officer. A prerequisite for an NEC 5311 assignment is the possession of an NEC 5342. The Saturation diver must be able to live and work at great depths for extended periods of time, conduct large object salvage to continental shelf depth, operate, maintain, and support SEALAB equipment systems and underwater salvage tools and equipment, and possess an extensive knowledge of marine life, ocean science, and mixed-gas scuba equipment. Master Divers, while assigned to the Saturation Program, shall retain their NEC 5341.

11 — Requirements for Divers First Class

A Designation—Divers first class are trained, qualified, and designated at the Naval School, Diving and Salvage, Washington, D.C. No man will be placed in training for diver first class at any other place without prior authority from the Chief of Naval Personnel.

B Eligibility requirements—Personnel must meet the following requirements to be eligible for the special course of instruction for diver first class—

1. Be recommended by his commanding officer.
2. Have a minimum obligated service of 18 months upon entry into the special course for diver first class.
3. Meet physical standards specified in article 15-30, Manual of the Medical Department, as required for diving duty.
4. Be a qualified swimmer first class.

C Qualification factors—The qualification factors are as follows—

1. Withstand pressure equal to 300 feet of water while breathing air.
2. Dive and accomplish work using self-contained underwater breathing apparatus (scuba), shallow-water diving equipment, deep-sea diving equipment, and helium-oxygen diving equipment.
3. Dive and accomplish work at a depth of 200 feet of water while breathing air.
4. Dive and accomplish work at a depth of 320 feet of water while breathing helium-oxygen mixture.
5. Demonstrate proficiency in the use of all underwater tools, both in the shop and under actual diving conditions; the operation and maintenance of a submarine-rescue chamber; and marlinespike seamanship commonly used aboard salvage and rescue vessels.
6. Demonstrate knowledge of diving physics, particularly showing proficiency in mixing and analyzing synthetic breathing mixtures and in computing pressures of gases required to operate underwater cutting torches at various depths.
7. Demonstrate knowledge of diving physiology; know the use of standard decompression tables; recognize symptoms of decompression sickness; and know the treatment required for all common diving accidents.
8. Demonstrate proficiency in the use of the recompression chamber for treatment of diving accidents and for surface-decompression procedures.
9. Care for, test, repair, and adjust all diving equipment and determine whether it is safe for use.
10. Equip a boat for both self-contained and surface-supplied diving.
11. Demonstrate ability to direct two or more divers on the bottom in their tasks.
12. Know the advantages, limitations, and techniques involved in the use of helium-oxygen, surface-supplied air, and self-contained diving apparatus.
13. Demonstrate ability to perform all required rigging for salvage and rescue operations.
14. Demonstrate ability to perform and supervise independent diving operations using surface-supplied air, helium-oxygen, and self-contained apparatus.
15. Plan simple diving operations.
16. Understand safety precautions necessary in handling of gases and use of apparatus required for underwater cutting.
17. Perform proficiently such underwater work as taking measurements, making templates, making fittings and placing shores, pouring cement, using excavating nozzles, and removing and repairing ship's appendages.

18. Maintain, rig, and operate salvage pumps, air compressors, winches, jacks, beach gear, and high line assemblies.
19. Rig for lifts encountered in salvage operations up to a maximum of 300 tons, including underwater lifts.
20. Install necessary pumps and air compressors, and lay necessary beach gear for hauling off stranded vessels. Understand in general the salvaging of vessels, including stability, structural strength, and groundings.
21. Enter submerged vessels with discrimination and only as decided and planned by the supervising officer.
22. Demonstrate proficiency in the use of explosives underwater and have knowledge of materials and methods used in such varied salvage activities as harbor clearance, harbor-bottom alteration, rock and concrete blasting, steel and timber cutting, and removal of propellors for replacement.

12—Requirements for Medical Deep-Sea Diving Technicians

A Designation—Medical deep-sea diving technicians are designated by the Bureau of Medicine and Surgery after satisfactory completion of the prescribed course of instruction at the Naval School, Diving and Salvage, Washington, D. C.

B Eligibility requirements—Personnel must meet the following requirements to be eligible for the medical deep-sea diving technician course of instruction—

1. Volunteer for and be recommended by his commanding officer.
2. Meet basic eligibility requirements as set forth in current BUMED directives.

C Qualification factors—Medical deep-sea diving technicians shall be required to meet the same qualifications as divers first class except as modified below—

1 Completely meet qualification factors 1, 2, 3, 4, 5, 9, and 10 above. Also demonstrate proficiency in the operation and maintenance of the submarine-rescue chamber.
2. Demonstrate more extensive knowledge and greater proficiency in qualification factors 6, 7, 8, 12, and 16 above.
3. Be exempt from qualification factors 11, 13, 14, 15, 17, 18, 19, and 20.
4. Demonstrate knowledge of health and safety aspects of the use of underwater tools, the entering of submerged vessels, and use of explosives under water.

13—Requirements for Salvage Divers

A The classification—This diver classification is being retained only as a category for expansion in event of an increase in diver requirements on mobilization; consequently, initial training of salvage divers has been discontinued.

B Eligibility requirements—Personnel must have satisfactorily completed the prescribed course in ship salvage.

C Qualification factors—The qualification factors are as follows—

1. Withstand pressure equal to 200 feet of water while breathing air.
2 Demonstrate mechanical ability.
3 Dive and accomplish work using self-contained underwater breathing apparatus (scuba), shallow-water diving equipment, and deep-sea diving equipment.
4. Demonstrate proficiency in the operation and care of machinery and apparatus required for underwater cutting, including oxygen-hydrogen and oxygen-electric torches under water.
5. Understand safety precautions necessary in handling of gases and use of apparatus required for underwater cutting.
6. Perform proficiently such underwater work as taking measurements; making templates; making, fitting, and placing patches; placing shores; pouring cement; using excavating nozzles; and removing and repairing ship's appendages.
7. Maintain, rig, and operate salvage pumps, air compressors, winches, jacks, beach gear and high line assemblies.

8 Rig for lifts encountered in salvage operations up to a maximum of 300 tons, including underwater lifts.
9. Install necessary pumps and air compressors, and lay necessary beach gear for hauling off stranded vessel. Understand in general the salvaging of vessels, including stability, structural strength, and groundings.
10. Enter submerged vessels with discrimination, and only as decided and planned by the supervising officer.
11. Demonstrate proficiency in the use of explosives under water and have knowledge of materials and methods used in such varied salvage activities as harbor clearance, harbor-bottom alteration, rock and concrete blasting, steel and timber cutting, and propellor removal and replacement.
12. Demonstrate knowledge of diving physics and of diving physiology; know the use of standard decompression tables; recognize symptoms of decompression sickness; and know the treatment required for all common diving accidents.
13. Demonstrate proficiency in the use of the recompression chamber for treatment of diving accidents and for surface decompression procedures.
14. Care for, test, repair, and adjust all diving equipment and determine whether it is safe for use.

NOTE

Salvage divers will not dive beyond the depths for which qualified, as stated in their service record, except for qualification purposes which will be limited to maximum depths of 200 feet. In emergencies, the senior officer shall be the judge of a deviation from the above.

14 — Requirements for Divers Second Class

A Designation — Divers second class are trained, qualified, and designated by any command having the proper equipment and competent personnel for safe and efficient instruction so designated by the Chief of Naval Personnel.

The following personnel and equipment are required on vessels and naval stations authorized to train, qualify, and designate divers second class—

A designated diving officer.

A master diver or diver first class who will serve as an instructor.

In general, the amount of equipment will depend upon the number of personnel being trained and qualified, but the minimum equipment shall include the following—

—Two deep-sea diving outfits.

—Two lightweight diving outfits.

—Three open-circuit demand self-contained underwater breathing apparatus.

—One recompression chamber (shall be on board ships authorized to conduct such training or, in the case of authorized activities, shall be in the nearby area).

—Sufficient copies of the Diving Manual, NAVSHIPS 0994-001-9010, that there will be one for each trainee.

—Copies of curriculum for divers second class, NAVPERS 93206.

B Eligibility requirements — Enlisted personnel in pay grade E-3 and above who are qualified as swimmers first class, and meet the physical standards for duty as set forth in Article 15-30, Manual of the Medical Department, U. S. Navy, are eligible.

C Qualification factors — Qualification factors for divers second class are as follows—

1. Understand the care, preservation, and use of all air diving equipment such as compressors, hose, helmets, suits, and scuba.
2. Test, repair, and adjust all air diving equipment and determine whether it is safe for use.
3. Know the nomenclature of diving equipment and the function of component parts.
4. Dress and tend diver expertly.
5. Know standard diving signals.
6. Know the instructions for keeping diving log and entries required.

7. Understand the theory and practice of decompression, and use of the decompression table.
8. Know the cause, symptoms, treatment, and prevention of air embolism.
9. Know the dangers of oxygen poisoning during the administration of oxygen under pressure, and its usual symptoms, warnings, and treatment.
10 Demonstrate the mouth-to-mouth method of artificial respiration.
11 Knowledge of first aid related to the treatment of common diving accidents.
12. Know the physics of diving.
13. Know the methods and procedures employed in searching for and recovering objects from the bottom.
14. Know how and when to use a recompression chamber. Know how to properly administer oxygen for decompression and treatment purposes.
15. Demonstrate practical application of marlinespike seamanship to diving operations.
16. Perform work at depth of 50 feet of water for 1 hour, which will constitute a qualifying dive.
17. Know the contents and use of the Diving Manual.
18. Estimate an underwater situation and give an intelligent description of same. Training and examination of this ability requires a number of actual or simulated practical diving jobs, such as applying small patches, clearing screws, and taking measurements.
19. Use oxygen-electric torch underwater.
20. Use and know the advantages, limitations, and safety precautions of open-circuit demand scuba.

NOTE

Divers second class will not dive beyond the depths for which qualified as stated in their service record, except for qualification purposes which will be limited to maximum depths of 200 feet. In emergencies, the senior officer present shall be the judge of a deviation from the above.

15 — Requirements for Scuba Divers

A Designation—Personnel are trained and designated as scuba divers at the U. S. Naval School, Underwater Swimmers, U. S. Naval Station, Key West, Fla., and such other activities specifically authorized by the Chief of Naval Personnel.

B Training requirements—The following personnel are required to be on board ships and naval activities authorized, in accordance with subparagraph A above, to conduct training in the use of scuba equipment—

1. A designated diving officer assisted by an experienced scuba diver or above who will serve as an instructor.
2. Sufficient copies of the Diving Manual, NAVSHIPS 0994-001-9010, so that there will be one for each trainee.
3. Copies of curriculum for scuba divers, NAVPERS 93206.
4. Recompression chamber (shall be on board ships authorized to conduct such training or in the case of authorized activities shall be in the nearby area).

C Eligibility requirements—Candidates must meet the following qualifications—

1. Enlisted personnel in pay grade E-3 and above, who are designated strikers or petty officers in one of the source ratings specified in the Bureau of Naval Personnel Formal Schools Catalog, NAVPERS 91769 (current series).
2. All personnel must meet the physical and psychological standards prescribed in Article 15-30, Manual of the Medical Department, U. S. Navy; must be at least swimmers first class; and must comply with selection standards for diving candidates.

D Qualification factors—Qualification factors for scuba divers are as follows—

1. Swim 1,000 yards on surface in open water without fins but with face mask, lifejacket, and knife as necessary equipment.
2. Swim 500 yards under water using fins, face mask, and scuba.

3. Clear scuba under water.
4. Ditch and don scuba under water.
5. Make a positive-buoyancy free ascent from a depth of at least 35 feet.
6. Swim with scuba to a depth of 100 feet.
7. Conduct day and night general underwater search and detailed ship-bottom search.
8. Use underwater compass, depth indicators, and associated underwater equipment.
9. Perform routine inspection, adjustment, field and shop maintenance on scuba and underwater accessories.
10. Know safety precautions to be observed in use of scuba.
11. Understand the theory and practice of decompression, and use decompression tables.
12. Knowledge of divers' diseases including oxygen and carbon dioxide toxicity, nitrogen narcosis, decompression sickness, and air embolism; and of emergency remedial procedures.
13. Know underwater hazards.
14. Understand use of current and tide tables.

NOTE

Scuba divers will not dive beyond the depths for which qualified in their service record. Normal working depths for scuba divers breathing compressed air is considered to be less than 130 feet.

16—Records

All diving-type activities will submit diving log-accident/injury reports in accordance with OPNAV-INST 9940.2 series.

17—Substantiation of Entitlement to Special Pay for Diving Duty

A personnel diary entry of Military Pay Order (DD Form 114) will be submitted in accordance with provisions contained in the Navy Comptroller Manual. In addition, in all instances wherein special pay for diving is affected, a concurrent page 13 entry will be made in the service record of the individual concerned.

APPENDIX F

SHIP REPAIR SAFETY CHECKLIST

DIVE SAFE

REPORT OF DIVING OPERATIONS

Prior to commencing diving operations and every 30 minutes thereafter, pass the following word over the 1MC. (OMIT COMPONENTS NOT APPLICABLE)

"THERE ARE DIVERS WORKING OVER THE SIDE, DO NOT OPERATE ANY EQUIPMENT, ROTATE SCREWS, CYCLE RUDDER, PLANES OR TORPEDO TUBE SHUTTERS, TAKE SUCTION FROM OR DISCHARGE TO SEA, BLOW OR VENT ANY TANKS, ACTIVATE SONAR OR UNDERWATER ELECTRICAL EQUIPMENT, OPEN OR CLOSE ANY VALVES OR CYCLE TRASH DISPOSAL UNIT BEFORE CHECKING WITH THE DIVING SUPERVISOR ______________________."
(NAME, RATE)

Upon Completion Of Diving Operations, Pass The Following Word Over The 1MC

"DIVING OPERATIONS ARE COMPLETED, NORMAL AND ROUTINE WORK MAY BE CARRIED ON IN ACCORDANCE WITH PREVIOUS INSTRUCTIONS."

START DIVING OPERATIONS

DIVING OPERATIONS WILL COMMENCE AT ____________ ON THE ______________ ____________
TIME SHIP DATE

NATURE OF DIVING OPERATIONS ______________________________

No particular sequence is required in signing diving form. Upon completion of all notifications and actions the Diving Supervisor will indicate he is satisfied that safe operations can commence by signing at the bottom of the checkoff list. In event there is a delay in the commencement of diving operations each signature of the checkoff list will be informed.

Signing of this checkoff list will indicate that the individual has been advised of the diving operation and that he has completed required actions to insure that "SAFETY" of the divers will not be jeopardized.

Diving operations will not commence until all signatures required are received and this form returned to the Diving Supervisor.

Below, indicated personnel sign form prior to commencing and upon completion of diving operations.

PRIOR COMMENCE	TIME	COMPLETION	TIME
Repair Activity			
Repair Officer			
CDO			
OOD			
SQD. OPS. OFF.			
Ships Alongside			
OOD			
OOD			
OOD			
OOD			
Ship Being Worked On			
ENG. OFFICER			
OOD			
Tag Out:			
Rudder			
Planes			

PRIOR COMMENCE	TIME	COMPLETION	TIME
Torpedo Shutters			
Trash Disposal Unit			
Tank Blows			
Tank Vents			
Shaft Locked			
Sea Suctions			
Sea Discharges			
U/W Electrical Equipment			
Sonars			
Other U/W Equipment Not Listed			
Appropriate Diving Signal Displayed			
Appropriate Diving Signal Removed			

____
DIVING SUPERVISOR (Signature)

REMARKS: ______________________________

____
DIVING OFFICER (Signature)

REMARKS: ______________________________

APPENDIX G

NAVSHIPS PUBLICATIONS

NAVSHIPS	Title
0900-004-800	Refloating the USS MISSOURI
0900-008-3010	Ship Salvage Survey for SEASIA, Indian Ocean Areas and Australia
099-028-2010	Material Certification Procedures and Criteria Manual for Manned Non-Combatant Submersibles
0911-000-5010	Instructions for Installation and Operation of Air Seal Cofferdam
0925-000-1000	U. S. Navy Towing Manual (Vol. 1 & 2)
0929-000-8010	Underwater Welding and Cutting Manual
0938-011-4010	Nuclear Powered Submarine Atmosphere Control
0941-010-5010	Series 2, 3, 4 and 6V-53 Industrial Engines and Power Units for U. S. Navy Salvage Equipment
0947-066-7010	Installation, Operation, Maintenance and Repair Instructions for Model 25034B, 25 h.p. Pump on Skid Assembly, Part No. 8-19900
0949-014-3010	Electrical and Mechanical Equipment Manual for 3000 PSI, 3.5 to 4.0 CFM, Portable Divers Breathing Air, Power Driven, Reciprocating Compressor Part No. 890703
0993-001-4000	Oxygen Breathing SCUBA Gear
0994-000-3010	U. S. Navy Salvage Manual—Part 1—Theory of Strandings and the Use of Beach Gear
0994-000-3020	U. S. Navy Salvage Manual—Part 2—Submarine Salvage
0994-000-8010	Submarine Salvage, Pontoons and Related Equipment
0994-001-0010	Power Pack Technical Manual
0994-001-1010	Operation and Maintenance for Swimmer Delivery Vehicle
0994-001-3010	Salvage of the USS LaFAYETTE
0994-001-4010	Salvage of the Drydock AFDM-2
0994-001-5010	Report of Aircraft SALVOPS MED (Executive Summary)
0994-001-6010	A Survey of Collapsible Pontoons
0994-001-7010	Use of Magnets in Marine Salvage
0994-001-8010	Ship Salvage Safety Manual
0994-002-0010	Ship Salvage Resources Survey, Panama Canal Zone Waters
0994-060-7010	Ship Salvage Operations—Miscellaneous Techniques
0994-002-6010	USS FRANK KNOX (DDR-742)—Stranding Salvage
0994-002-7010	Foam - in - Salvage — Urethane Foam Flotation Methods and Equipment
0994-002-8010	The Salvage of the Dredge JAMAICA BAY
0994-003-5010	SDV Technical Manual, Mark VII Mod 2
0994-003-7010	U. S. Navy Diving Gas Manual
0994-004-5010	ALVIN SALVOPS Report
0994-004-6010	Free Fall Deep Mooring System
0994-004-8010	Carpenter Stopper Operation and Maintenance Instructions
0994-007-1010	Explosive Anchor Handling Manual
0994-007-3010	Recompression Chamber Demand Breathing System
0994-007-4010	Aqua-Lung UBA
0994-007-5010	Divers' Hot Water Heating System
0994-007-7010	Hyperbaric Facilities; General Requirements for Material Certification
0994-007-8010	Underwater Work Techniques Manual
0994-008-0010	Self-Contained UBA–Double Tank
0994-008-1010	ARROW—Report of Salvage Operations and Oil Pollution Control Measures
0994-009-6010	Diving Operations Handbook
0994-010-4010	Hyperbaric Facilities Directory (Vol. 1 & 2)
0994-010-7010	Deep Ocean Search Manual
0994-011-2010	SQUAW Mooring Manual
0994-012-0010	SDV Communication System

0994-012-1010	Grapple for use for CURV
0994-012-3010	Diver Equipment—General Requirements for Material Certification
0994-012-4010	ESSM Manual
0994-012-5010	Breathing Gas Supply Systems—General Requirements for Material Certification
0994-012-6010	Salvage Operations
0994-012-7010	Contingency Plan for Abatement of Major Navy-Originated Spills of Oil and Hazardous Material
0994-013-3010	Systems Certification for Safety of Deep Submergence Systems
0994-014-5010	U. S. Navy Recompression Chamber Operator's Handbook

APPENDIX H

GAGE CALIBRATION PROCEDURES

CALIBRATION OF GAGES

Serious difficulties in diving can arise from the use of inaccurate gages. This is particularly true with gages employed to determine depth pressure, as on a recompression chamber or pneumofathometer. A relatively small error could result in improper decompression of a diver.

All gages must be checked at least once every 12 months in accordance with NAVSHIPS Technical Manual, chapter 87-14, unless a malfunction requires repair or calibration more frequently.

When oxygen systems are being cleaned, gage lines should be removed and cleaned separately, after first cleaning the system with them attached. This is done to insure that the gage lines are thoroughly flushed. All gages must be removed from the system prior to the cleaning process to avoid dead ends in the system, and damage to the gage due to the heated detergent solution.

Calibration of Sea-Water Depth Gages—Depth gage readings in feet of sea water are especially important in diving. Since almost all gage testers are graduated in pounds per square inch, conversions are needed. It is helpful to make up a conversion table in appropriate increments, giving pounds per square inch in one column and the corresponding depths in another.

An appropriate number of points should be checked depending on the scale of the gage and the increments available with the tester.

Example—

1. If the gage scale is in 1-foot increments, check 10-psi increments of pressure to obtain readings for 22½, 45, 67½, 90, etc., feet.
2. If the gage is marked off in 2-foot or 5-foot increments, 20-psi steps of pressure (45, 90, 135 feet, etc.) should be sufficient.

At each increment of pressure, the actual reading of the gage being tested should be recorded, together with the true depth that corresponds to the pressure.

In testing a gage, it is desirable to run more than one test (or at least to note readings both with increasing and decreasing steps of pressure) to check the consistency of errors. A gage that shows large or variable errors, or one that sticks excessively, should be turned over for repairs or surveyed.

An attempt may be made to adjust a gage according to article 87-17 of the NAVSHIPS Technical Manual. If this is not done or is not wholly successful, a calibration curve (graph) or table must be prepared to indicate the relationship between true depths and gage readings. If the deviations are within 5 feet of true depth and vary less than 2 feet in a 50-foot change of depth, 50-foot increments must be used in the calibration table. If the deviations are greater than this, 10-foot increments must be used. (In such a case, readjustment, repair, or replacement of the gage is actually preferable).

TABLE H-1
DEPTH GAGE CALIBRATION

DEPTH GAGE #2 USS PENGUIN

Calibrator, initials True depth, f.s.w.		Calibration date Gage reads, f.s.w.	
0		0	
50		49	Variation
100		98	less than
150	50 foot increments	148	2 feet in
200		199	any 50 foot
250		250	increment.
300		301	
350		352	Variation
360		362	greater
370	10 foot increments	372½	than 2
380		382½	feet in
390		393	50 foot
400		403	increment

The calibration table should be affixed to the inside of the gage face glass. It should resemble the sample in Table H-1 and should include this information—

- —Identification of depth gage.
- —True depths in feet.
- —Corresponding actual gage readings.
- —Name of ship or activity.
- —Initials of individual responsible.
- —Date of calibration.

In using a gage with such a table, some interpolation is necessary. For example, the gage whose calibration table is shown in Table H-1 could be expected to read about 275½ for a true depth of 275 feet, or to indicate a true depth of about 323½ when it reads 325 feet. For most purposes, such estimates are sufficiently accurate. A calibration graph, with true depth on one axis and actual reading on the other, would permit more exact and more rapid corrections.

Roylyn Gages—Rucker Precision manufactures two basic types of gages for use on recompression chambers. Both are direct drive instruments employing a helical bourdon tube as the sensing element. The gages are accurate to ¼ of 1% 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 dial adjustment screw mounted on the front face of the gage provides for zero point adjustment and special set pressure. Dial readout can be in PSI and/or Ft. of seawater.

APPENDIX I

DANGEROUS MARINE ANIMALS

MARINE ANIMALS THAT BITE I.I

SHARKS

White Shark
Distribution — Widespread oceanic distribution, mostly in tropical, subtropical or warm water temperature areas. Numerous in Australian waters.

Appearance—Slate brown, slate blue, dull grey, or almost black above. Dirty white underneath. Small black spots with black fin tips. Larger white sharks are sometimes dun-colored or leaden white.

Hazard—One of the most dangerous and has even been known to attack boats. Aggressive and fast, with a history of numerous attacks on humans.

Mako Shark
Distribution—Oceanic species found in tropical waters or warmer waters of the Atlantic. Varieties of species are found in the Pacific.

Appearance—Teeth are prominent. Slender form. Color is deep blue grey, bright blue, or deep blue above. White underneath. Up to 13 feet long.

Hazard—Savage and dangerous. Fast. History of human attack, classified as a game fish, and has been known to attack boats.

Porbeagle Shark
Distribution—Continental waters of the North Atlantic, Mediterranean, N. W. Africa, North Sea, Northern British Isles, Atlantic coast of U. S. and some Scandinavian regions.

Appearance—Teeth are prominent. Dark, bluish grey above. Lower sides change to white. Anal fin is white or dusky. Dusk tips on pectoral fins. Up to 12 feet long.

Hazard—Active when in pursuit. Otherwise sluggish.

Tiger Shark
Distribution—Widespread in all tropical and warm belts of all oceans. Inshore and offshore. Most common shark in tropics.

Appearance—Prominent teeth, short snout, sharply pointed tail. Grey or greyish brown, darker above. Striping usually only on smaller fish. Up to 15-20 feet long.

Hazard—Mostly a scavenger. Fast in pursuit, usually sluggish otherwise. Some human attacks.

Lemon Shark
Distribution—Often found in inland waters, saltwater creeks, bays and sounds. Commonly active near docks. Inshore Western Atlantic, Carolinas, Northern Brazil, tropical West Africa.

Appearance—Second dorsal fin that is almost as large as the first. Broad, round snout. Prominent teeth. Yellowish brown above, occasionally dark blue grey above, sides and belly yellow. Up to 11 feet long.

Hazard—Unpredictable, with some history of human attack.

Lake Nicaragua Shark
Distribution—Freshwater species confined to fresh waters and shallow areas of Lake Nicaragua and tributaries (also outlet).

Appearance—Dark grey above, light below. Up to 10 feet long.

Hazard—Some history of human attack; unpredictable.

Dusky Shark
Distribution—Often found in shallow waters in warm temperature zones on both sides of the Atlantic.

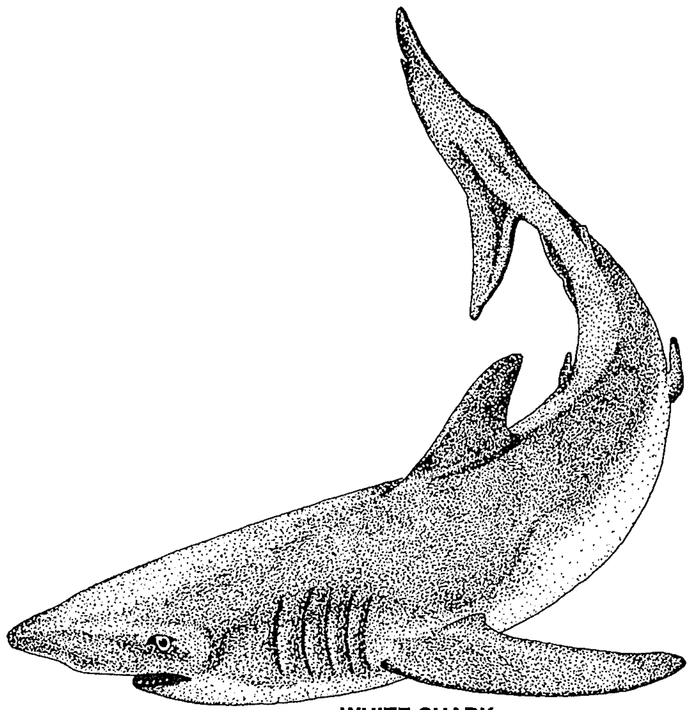
Appearance—Back and upper sides are usually leaden grey or bluish. Lower parts are white. Up to 14 feet long.

Hazard—Unpredictable. Fearless.

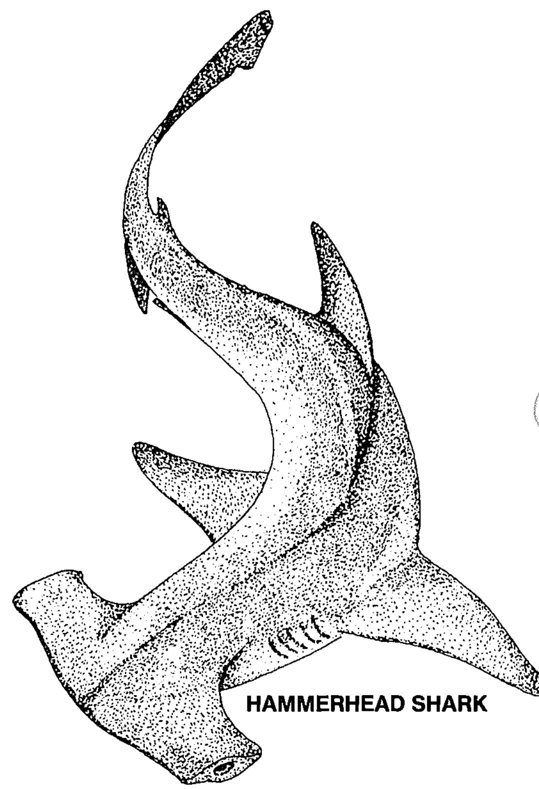
White-Tipped Shark
Distribution—Tropical and subtropical Atlantic and Mediterranean. Also found along Iberian Peninsula. Found in deep offshore waters.

Appearance—Short snout, rounded dorsal fin. Light grey to pale brown to slate blue above. Whitish color below. Some spotting, and in some species white tips on fins. 13 feet or longer.

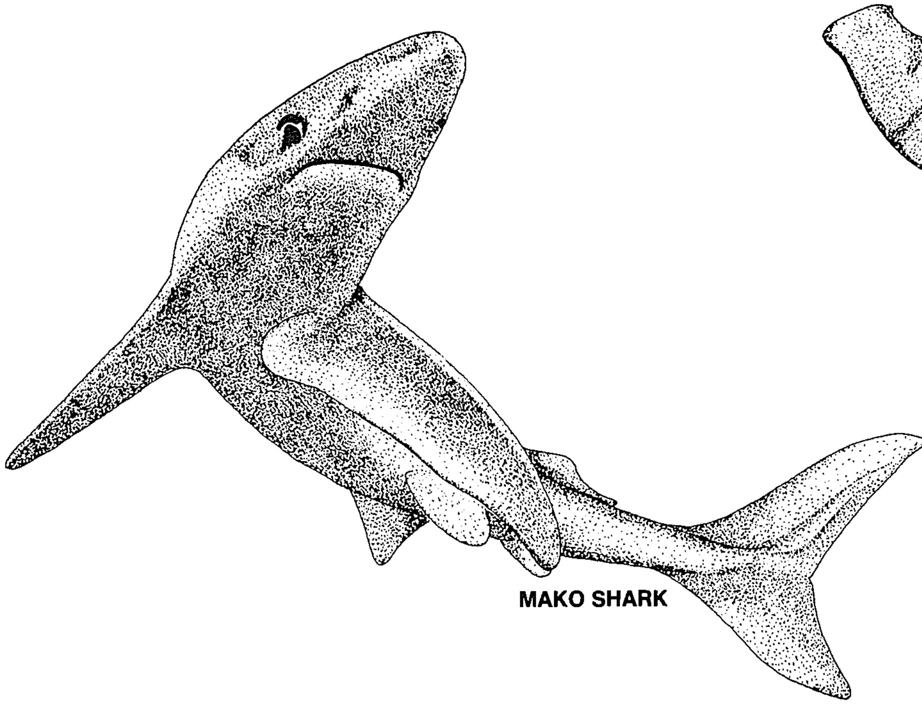
Hazard—Fearless in contact with man. Indifferent. Record of human attack.



WHITE SHARK



HAMMERHEAD SHARK



MAKO SHARK

Sand Shark

Distribution—Shore species living on or near the bottom. Inhabits the Mediterranean, West Africa tropical zones, Canaries and Cape Verdes in North Atlantic, South Africa, Western Atlantic from Maine to Florida. Southern Brazil. Similar species in Pacific Indian areas and Argentine waters.

Appearance—Five gill openings in front of fins. Two fairly equally-sized dorsals. Teeth are prominent. Bright color, grey brown above, dark along back. Pale on sides, with grey white on belly and lower sides of fins. Rear body often marked with spots. Up to 10 feet.

Hazard—Fairly sluggish but with an active appetite. North American species are generally harmless, but sharks in Indian Ocean and some tropical areas can be dangerous.

Gray Nurse Shark

Distribution—Coastal waters as well as open sea regions near Australia.

Appearance—Dull pale grey to dirty pale brown. Large dorsal fin and prominent teeth. 9 feet or longer.

Hazard—Aggressive and savage. Extensive record of human attack.

Ganges River Shark

Distribution—Indian Ocean to Japan, often penetrating into fresh-water rivers.

Appearance—Grey above, dull white below. Up to 7 feet long.

Hazard—Ferocious with large record of human attack.

Hammerhead Shark

Distribution—Both in offshore and inshore waters. Often seen swimming on surface. Found in varying species in all tropical and warm zones of all oceans and seas.

Appearance—Obvious hammer head shape. Eyes on outer edges. Ashen grey above fading to white below. Up to 15 feet long.

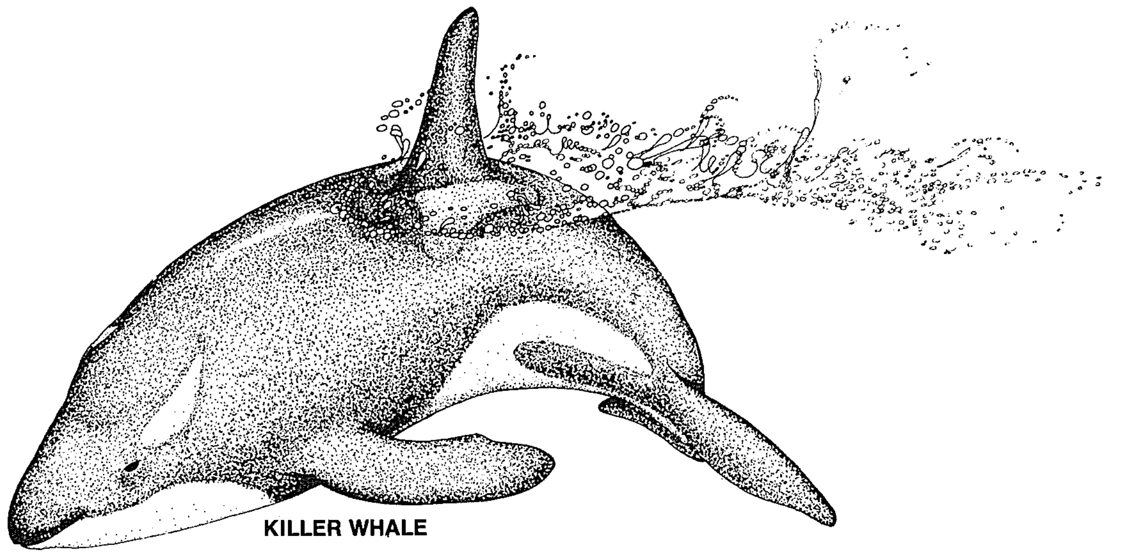
Hazard—Powerful, known to attack man.

PREVENTION—

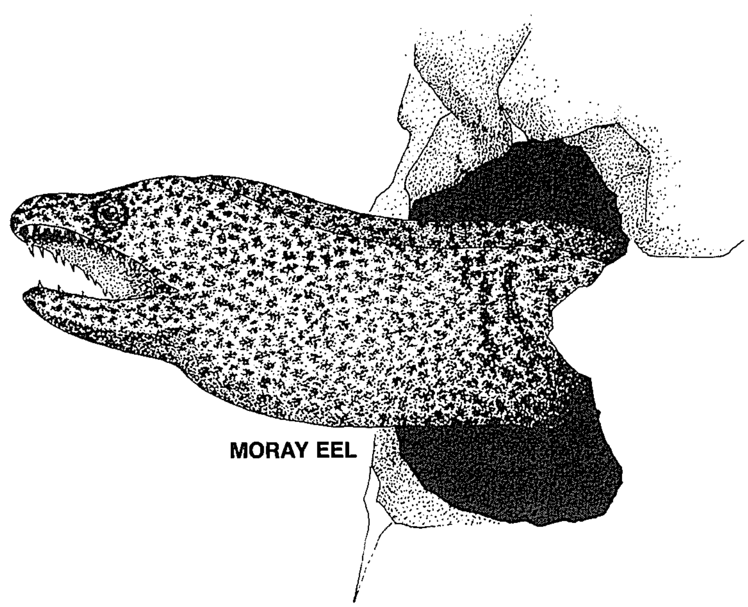
1. Making noise, blowing bubbles, etc. are of questionable value. Some noise attracts sharks.
2. Slow, purposeful movements should be used. Often, remaining absolutely still is best.
3. Often sharks can be "shoved" away with a large stick or "shark billy."
4. Attempts to kill or wound a shark are usually more dangerous than effective.
5. In striking a shark, concentrate on snout, eyes or gills.
6. Dark colored clothing and instruments are preferable.
7. Explosions, flashing lights, noise, or thrashing all can attract sharks.
8. Do not swim with open wounds. Do not dangle legs or arms in water. Enter and leave boats quickly.
9. Do not throw food, waste, or any food refuse overboard if sharks are suspected to be in the area.
10. The use of firearms by "swim-sentries" should be with extreme caution. Automatic weapons or hand guns should never be employed.
11. Avoid situations of an isolated swimmer. Groups of divers are in a better position to ward off attack.

TREATMENT—

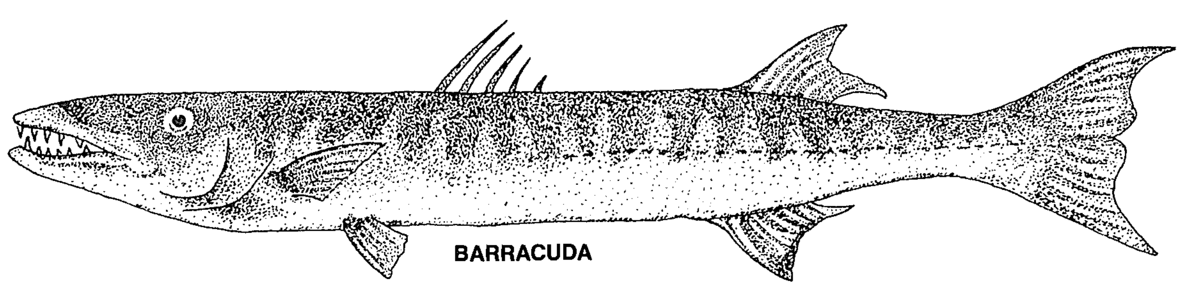
1. Bites from sharks are severe, with an extremely high rate of fatality (50-80%). Abrasions can result from contact or brushing up against a shark.
2. Bites result in large amount of bleeding and tissue loss. Immediate action should be taken to control bleeding using large gauze pressure bandages. Wounds should be filled with gauze and material held in place by elastic bandages.
3. Treat for shock immediately after (or while) bleeding is being managed.
4. Hospitalization and transfusions are required in virtually all cases.
5. Wounds should be cleaned as soon as possible, and advanced surgical procedures, such as primary closure and skin-grafting accomplished within as rapid a time as possible.



KILLER WHALE



MORAY EEL



BARRACUDA

OTHER FISH

Barracuda

Distribution—West Indies, tropical waters, Brazil, north to Florida, and in the Indo-Pacific from the Red Sea to the Hawaiian Islands.

Appearance—Long, thin fish with prominent jaws and teeth. Silver to blue in color. Large head. V-tail. Small to large size which can be from 6 to 8 feet long.

Hazards—20 odd species that vary in their danger. In some regions these fish are more dangerous than sharks. Exceedingly fast swimmers, striking rapidly and fiercely at anything that enters the water. Will follow swimmers but will seldom attack an underwater swimmer. Known to attack surface swimmers and limbs dangling in the water.

PREVENTION AND TREATMENT—

1. Barracuda wounds can be differentiated from those of a shark by their tooth pattern. Barracuda leave straight cuts, while those of a shark are curved like the shape of their jaws.
2. Barracuda are attracted by any bright object, and will also strike a speared fish carried by a diver. Splashing or any flurry of activity can also stimulate a Barracuda to attack.
3. Treatment is the same as for shark bites.

Moray Eels

Distribution—Confined to tropical and subtropical waters. Some temperate zone species are known. Bottom dwellers. Commonly found in holes, crevices, under rocks or coral.

Appearance—Snake-like in appearance and swimming. Tough leathery skin. Can attain a length of 10 feet. Teeth are prominent.

Hazard—Extremely hazardous. Will attack readily and easily provoked. Powerful and vicious biters.

PREVENTION AND TREATMENT—

1. Bites from Moray Eels are of the tearing jagged type.
2. Extreme care should be used when diving in rocky areas, entering caves or reaching into blind holes.
3. Treatment is the same as for shark bites.

MAMMALS

Sea Lions

Distribution—Numerous on West Coast of United States and similar locales. Predominant in Pacific Ocean.

Appearance—Resemble seals but are larger.

Hazard—Normally harmless. However during the breeding season, large bull sea lion can be irritated and will nip at divers. Divers should generally avoid these mammals when in the water.

Killer Whales

Distribution—Found in all oceans, tropical and polar.

Appearance—Large mammal, with a blunt, rounded snout. High black dorsal fin. Usually, a white patch can be seen behind and above the eye. Sharp contrast between jetblack head and back, and snowy white undersides. Usually observed in packs of from 3-40 whales.

Hazard—Killer whales are extremely ferocious. They have powerful jaws, great weight, speed, and interlocking teeth. They will attack anything in the water without hesitation.

PREVENTION AND TREATMENT—

If killer whales are spotted all personnel should immediately leave the water. In addition, extreme care should be taken on shore areas, docks, barges, ice floats, etc. when the whales are in proximity.

MARINE ANIMALS THAT STING I.2

VENOMOUS FISH

Local—Found throughout the world, most common in tropical waters.

Appearance—Varies, but most tend to be ugly.

Hazard—Venom of varying effects, usually carried in spines.

Catfish

Distribution—Usually fresh water, found worldwide.

Appearance—Varies, but lips usually equipped with long barbels; skin is thick, no scales.

Hazard—Venom in spines in dorsal and pectoral fins.

Weever Fish
Distribution—Temperate zone, Europe to North Africa.

Appearance—Small fishes (to 18″), usually seen buried in the mud with only the head exposed.

Hazard—Spine on cheek, used as a weapon in hunting for food. Aggressive.

Scorpionfish (including Zebrafish and Stonefish)
Distribution—Widely distributed in temperate and tropical seas; some in artic waters. Shallow water, bottom dwellers.

Appearance—Gaudy, ugly, ornate.

Hazard—Stings in fins; fearless; some venom is deadly.

Toadfish
Distribution—Warmer coastal waters, worldwide.

Appearance—Broad, depressed heads, large mouths, repulsive looking.

Hazard—Dorsal and gill cover venomous spines; fish often camouflaged.

Surgeonfish
Distribution—Along reefs in warm seas.

Appearance—Short and vertical; full dorsal and anal fins.

Hazard—Sharp spine at base of tail fin.

Rabbitfish
Distribution—Indo-Pacific.

Appearance—Similar to surgeonfish.

Hazard—Spine in dorsal, pelvic and anal fins (total 24).

Ratfish
Distribution—One type in European waters; one type along Pacific Coast of North America.

Appearance—Rounded snout; laterally compressed body tapering to a slender tail.

Hazard—Single large venom spine at first dorsal fin.

PREVENTION AND TREATMENT—

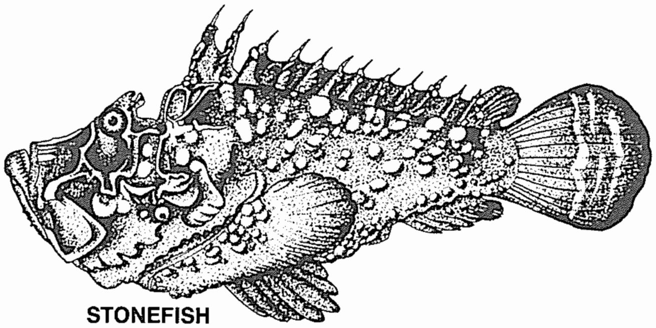
1. Avoid handling fish.
2. Get victim out of water; watch for possibility of fainting.
3. Observe for signs of shock.
4. With large sting, wash wound with salt water (cold) or sterile saline.
5. Try to remove venom by sucking; make small incision to open wound if necessary.
6. A tourniquet may be of help to prevent spread of the venom; if used, it should be placed between the wound and the heart, as near the wound as possible. It must be released frequently to avoid cutting off circulation.
7. Soak wound in hot water for 30-60 minutes.
8. Heat from the water may break down the venom—have the water as hot as the victim can tolerate. Use hot compresses if wound is on the face.
9. Addition of magnesium sulfate or Epsom salts to water may help.
10. Local injection of 0.5 to 2% Procain may help; if this fails, intramuscular or intravenous demerol may help.
11. When pain has subsided, cover wound and elevate if possible. Get medical assistance.

Stingrays
Distribution—Common in all tropical, subtropical, warm and temperate regions in varying species. Usually favor sheltered water, burrow into sand with only eyes and tail exposed.

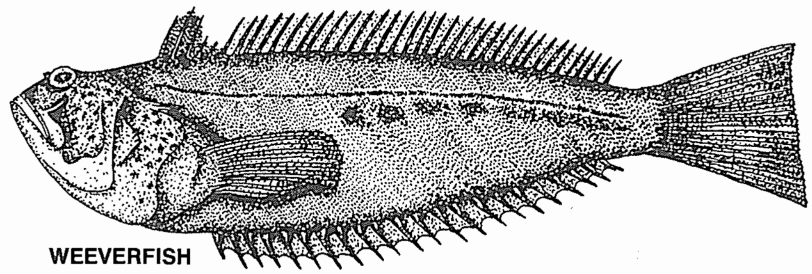
Appearance—Bat-like shape with a long spine or tail.

Hazard—Wounds are either of the laceration or puncture type. Symptoms can include a fall in blood pressure, vomiting, diarrhea, sweating, rapid heart beat, muscular paralysis, extreme pain, and death has occasionally been reported.

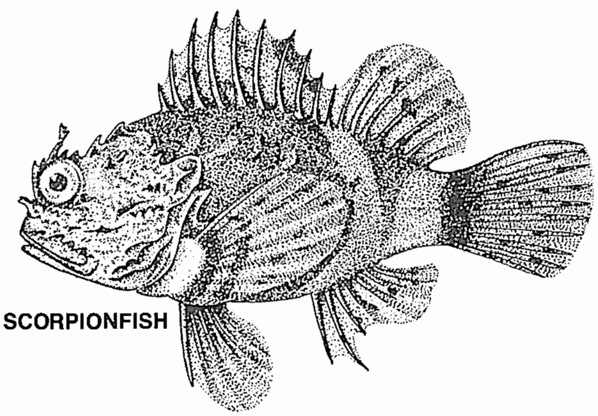
PREVENTION AND TREATMENT—
No known antidote, see fish sting for general treatment.



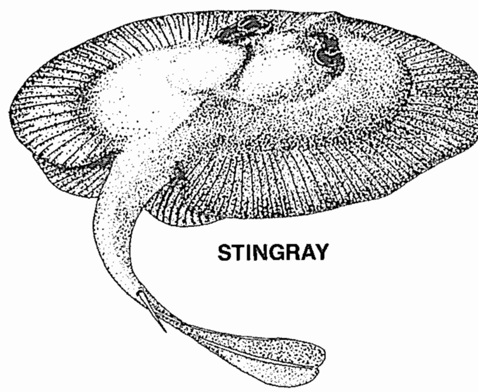
STONEFISH



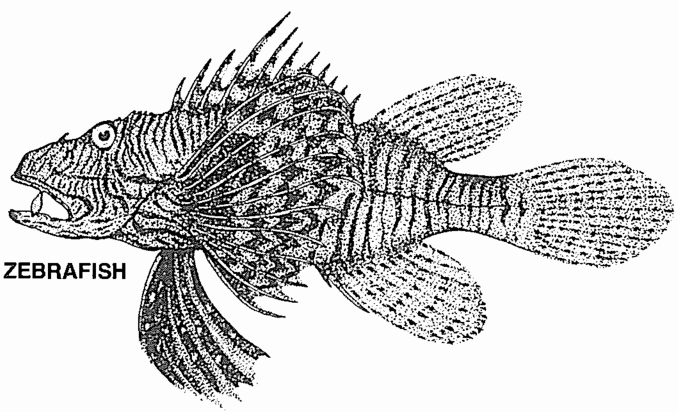
WEEVERFISH



SCORPIONFISH



STINGRAY



ZEBRAFISH

Horned or Spiny Sharks (Dogfish)
Distribution—Both sides of the North Atlantic and North Pacific Oceans. Prefer shallow protected bays for habitat.

Appearance—Appearance is much like a rather small shark. Single spine is located in front of each dorsal fin.

Hazard—Immediate and intense stabbing pain. Have been known to be fatal.

PREVENTION AND TREATMENT—
Treat as any other fish sting.

OTHER ANIMALS

Corals (various)
Distribution—Tropical and subtropical waters.

Appearance—Porous, rock-like formation.

Hazard—Extremely sharp. The most delicate appearing corals are often the most dangerous, having razor sharp edges. Coral cuts, while usually fairly superficial, are very long in healing. Can cause a temporary disability. Some varieties of coral can actually "sting" a diver much like a jelly fish. Whether a cut or sting, the smallest wound, if left untreated, can develop into an ulcer coupled with an extensive sensitive red area.

PREVENTION AND TREATMENT—
1. Promptly cleanse the wound.
2. Remove all foreign particles.
3. Apply antiseptic agents.
4. Bed rest, elevation of the affected limb, and/or further medication is often required.
5. Extreme care should be used in working around coral. Often coral is located in a reef formation which is subjected to heavy surface water action, and both surface and bottom current. Surge also develops in reef areas. For this reason, it is easy for the unprepared diver to be swept or tumbled across coral with serious consequences.
6. Coral should not be handled with bare hands. Completely soled swim fins should also be used.

Jellyfish (including Portuguese Man-Of-War and Sea Wasp)
Distribution—Widespread species vary according to oceanic region. Hazardous types include: Sea Wasp, Sea Nettle, Sea Blubber, Sea Anemone, Rosy Anemone and Portuguese Man-Of-War.

Appearance—Blue, green or transparent in appearance. Balloon-like floats with tentacles dangling down into the water. The Sea Wasp and Portuguese Man-of-War are the most dangerous types.

Hazard—Hazardous jellyfish can come into direct contact with a diver in virtually any ocean region. When this happens, the man is exposed to literally thousands of minute stinging organs in the tentacles.

PREVENTION AND TREATMENT—
Jellyfish stings usually result in painful local skin irritations. However, ulceration of the skin can be severe. The Sea Wasp's sting can produce death in from 3-8 minutes. Symptoms can range from itching to blistering, to abdominal pain, to convulsions. Diluted ammonia and alcohol should be applied as soon as possible, and further medical attention sought.

Octopus
Distribution—Widespread in tropical and temperate zones. Species vary as to region. Grouping includes, nautilus, cuttlefish and squid.

Appearance—Large sac surrounded by eight or ten tentacles. Head sac is large with well-developed eyes. Horny jaws on mouth. Movement is made by jet action produced by expelling water from the mantle cavity through the siphon.

Hazard—Octopus hide in caves and crevices. They possess a well-developed venom apparatus, and sting by biting.

PREVENTION AND TREATMENT—
Octopus bites consist of two small punctures. Burning or tingling sensation results, and will soon spread. Bleeding is often severe. Clotting ability of the blood is often retarded. Swelling, redness and heat.

General treatment for controlling bleeding. No specific treatment.

APPENDIX J

GENERAL SAFETY CHECKLIST

STEPS IN PLANNING OF DIVING OPERATIONS

A. ☐ **ANALYZE THE MISSION FOR SAFETY**

Advanced planning is the **greatest single safety precaution** that can be taken.

- ☐ Objective definition
- ☐ Environmental conditions
- ☐ Emergency assistance
- ☐ Relevant NWP and OPNAV instructions

B. ☐ **PIN-POINT POTENTIAL HAZARDS**

☐ **Natural Hazards**

1. Atmospheric:
   - ______ Extreme exposure of personnel to elements.
   - ______ 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, petroleum disrupting operations
   - ______ Delays or disruption caused by sea state
3. Underwater and Bottom:
   - ______ Depth exceeds diving limits or limits of available equipment
   - ______ Exposure to cold temperatures
   - ______ Dangerous marine life
   - ______ Tides and currents
   - ______ Limited visibility
   - ______ Bottom obstructions
   - ______ Dangerous bottom conditions (mud, drop-offs, sewer outfalls, etc.)

☐ **"On-Site" Hazards**

- ______ Local marine traffic
- ______ High powered, active sonar
- ______ Other conflicting naval operations
- ______ Other conflicting commercial operations
- ______ Radiation contamination
- ______ Pollution

☐ **Mission Hazards**

- ______ Decompression sickness
- ______ Communications problems
- ______ Drowning
- ______ Other trauma (injuries)
- ______ Hostile action

☐ **Object Hazards**

- ______ Entrapment
- ______ Entanglement
- ______ Pollution, toxic
- ______ Explosives or other ordnance
- ______ Shifting or "working" of object

C. ☐ **MINIMIZE HAZARDS AND PLAN FOR EMERGENCIES**

☐ **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
______ Last record of medical exam
______ Ears and sinuses
______ Severe cold or flu
______ Use of stimulants or intoxicants
______ Fatigue
______ 5. Determine each man's **emotional** fitness to dive (as far as possible):
______ Motivation (willingness)
______ Stability

☐ **Diving Equipment**

______ 1. Verify that the type of diving gear chosen (and diving technique) is adequate for the mission and particular task.
______ 2. Verify that the type of equipment and diving technique is proper for the depth involved (see page 4-20).
______ 3. Verify that all equipment has been tested and approved for U. S. Navy use.
______ 4. Determine that all necessary support equipment and tools are readily available, and are the best for accomplishing the job efficiently and **safely.**
______ 5. Determine that all related support equipment such as winches, boats, cranes, floats, etc. are operable, safe, and under the 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 functioning.
______ 2. Verify that a recompression chamber is ready for use, or notify the nearest command having one that its use may be required within a given time frame.
______ 3. Verify that a First Aid kit is near at hand, and is completely stocked.
______ 4. If oxygen will be used as standby first aid, verify that the tank is full, properly pressurized, and that all masks, valves and other accessories are fully operable.
______ 5. If a resuscitator will be used, check the apparatus for function.
______ 6. Check that all 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. Assign specific tasks to the Diving Team and support personnel for different emergencies.
______ 3. Develop and **Post** the **Emergency Assistance Checklist,** and ensure that all personnel are familiar with it.
______ 4. Verify that a copy of the U. S. Navy Decompression Tables is available and up-to-date.

_____ 5. Be sure that all divers, boat crews, and other support personnel understand all diver hand signals.

_____ 6. Pre-determine distress signals and call-signs with all members of the diving team, boat crews, and other activities.

_____ 7. Be sure that all divers have removed anything from their mouths which might choke them during a dive (gum, dentures, tobacco).

_____ 8. Thoroughly drill and train all personnel in Emergency Procedures, with particular attention to cross-training. Drills should include:

Emergency Recompression	Rapid Undressing
Fire	First aid
Rapid Dressing	Embolism
Restoration of Breathing	Drowning
Electric Shock	Blow-Up
Entrapment	

D. ☐ **ESTABLISH SAFE DIVING OPERATIONAL PROCEDURES**

_____ 1. Determine that all **other** means of accomplishing the mission have been considered before deciding to use divers.

_____ 2. Be sure that contingency planning has been conducted.

_____ 3. Carefully state the goals of each mission, and develop a flexible plan of operations.

_____ 4. Completely brief the Diving Team and support personnel.

_____ 5. Designate a properly qualified Diving Supervisor to be in charge of the mission.

_____ 6. Designate a 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 or pneumofathometer.

_____ 8. Verify the existence of an adequate supply of compressed air available for all planned diving operations **plus** an adequate reserve for emergencies.

_____ 9. Be sure that no operations or action on the part of the Diving Team, support personnel, boat crews, technicians, winch operators, etc. may take place without the knowledge and by the direct command of the Diving Supervisor.

_____ 10. All efforts must be made through proper planning, briefing, training, organization, and other preparations to reduce and minimize "bottom-time." Remember in all cases, water depth and the condition of the diver (especially fatigue) rather than the amount of work to be done shall govern the diver's bottom time.

_____ 11. Decompression tables should be on hand, be up-to-date, and be used in all planning and scheduling of diving operations.

_____ 12. Instruct all divers and support personnel not to cut any lines until that action is approved by the Diving Supervisor.

_____ 13. Be sure that the ship, boat, or diving craft is securely moored and in position to permit the safest and most efficient operations (except in the case of emergency and critical ship repairs).

_____ 14. Verify that, when using surface-supplied techniques, that the ship, boat, or diving craft is in at least a two-point moor.

_____ 15. Ensure that, when conducting SCUBA operations, the boat can be quickly cast off and moved to a diver in distress.

_____ 16. Ensure that each diver checks his own equipment **in addition** to checks made by tenders, technicians, or other support personnel.

_____ 17. Designate a standby diver for all surface-supplied operations. And, check that the standby diver is dressed (including breastplate) and ready to enter the water if needed.
_____ 18. Assign buddy divers for all SCUBA operations.
_____ 19. All efforts should be made to prevent the divers from being fouled on the bottom. If work is to be conducted inside a wreck or similar underwater structure, designate a team of divers to accomplish the task. One diver will enter the wreck, the other shall tend his lines from the point of entry.
_____ 20. When using explosives, take appropriate measures to ensure that no charge will be fired while divers are in the water.
_____ 21. Use appropriate safety procedures as outlined in relevant naval publications for all underwater cutting and welding operations. (See Appendix G for listing of NAVSHIPS publications.)
_____ 22. Brief all divers and deck personnel on the planned decompression schedules for each particular dive. Check provisions made for decompressing the diver.
_____ 23. Verify that the ship, boat or diving craft is displaying the proper signals, flags, dayshapes, or lights to indicate diving operations are in progress. (Consult appropriate publications governing International or Inland Rules, International/Inland local signals, and proper Navy communications instructions.)
_____ 24. Ensure that proper protection against harmful marine life has been provided. If marksmen are used to protect against shark, verify that they do not have automatic weapons.
_____ 25. Check that the quality of diver's air supply is periodically and thoroughly tested to ensure purity.
_____ 26. For dives conducted from a small boat to a depth of 120 feet or greater, a standby air supply is mandatory.
_____ 27. Ensure that, when diving from a small boat to depths of 120 feet or greater, a standby boat is available at the scene.
_____ 28. Thoroughly brief the boat crew using the Diving Boat Operations Checklist.
_____ 29. Verify that proper safety and operational equipment is aboard small diving boats or craft (see Boat Equipment Checklist).

☐ **Notify Proper Parties that DiveOps Are Ready to Commence**

_____ 1. Diving Officer
_____ 2. Commanding Officer
_____ 3. Area Commander
_____ 4. Officer of the Deck/Day
_____ 5. Commanding Officer of Ships Alongside
_____ 6. Bridge, to ensure that ship's personnel **will not:**
    _____ Turn the propeller or thrusters
    _____ Get underway
    _____ Activate active sonar or other electronics
    _____ Drop heavy items overboard
    _____ Shift the moor
    _____ Operate rudder or steering mechanisms
_____ 7. Submarine Duty Officer, to ensure that submarine personnel **will not:**
    _____ Activate sea discharges or suctions
    _____ Operate bow or stern-planes or rudder
    _____ Operate vents or torpedo shutters

APPENDIX K

SURFACE-SUPPLIED DIVING OPERATIONS PRE-DIVE CHECKLIST

PRE-DIVE CHECKLIST

☐ **A. Basic Preparation**

- ☐ 1. Check that, for dives over 170 feet, a recompression chamber and diving medical officer are present on the diving station.
- ☐ 2. Verify that the proper signals indicating underwater operations are being conducted are properly displayed.
- ☐ 3. Make sure that all personnel concerned or in the vicinity have been informed that diving operations are underway.
- ☐ 4. Determine that all valves, switches, controls and equipment components that influence the diving operation are properly "tagged-out" to prevent inadvertent shut-down or activation.

☐ **B. Equipment Preparation**

- ☐ 1. Assemble all members of the diving team as well as support personnel (winch operators, boat crew, watchstanders, etc.).
- ☐ 2. Assemble and lay out all equipment that may be used on the dive, either as primary equipment or standby spares for the diver (or standby diver). This should include **all** accessory equipment and tools.
- ☐ 3. Check all equipment for superficial wear, tears, dents, distortion or any other apparent discrepancies.
- ☐ 4. Check all masks, helmets, viewing ports, faceplates, seals, and visors for broken glass or plastic.
- ☐ 5. Check all belts, laces, and lanyards for wear and renew as needed.

☐ **C. Deep-Sea Outfit**

- ☐ 1. Check the rubber gasket on all helmet faceplates for wear.
- ☐ 2. Check the interior of the helmet to insure that all controls and components are dry and free of verdigris. Pay special attention to terminals for the diver's communication system.
- ☐ 3. Check the threads on the goosenecks on the back of the helmets for breakage, verdigris or wear.
- ☐ 4. Check the safety locking device on the helmet for freedom of action, and verify that the locking gate on the breastplate recess has a **brass** cotter pin.
- ☐ 5. Check that all studs on the breastplate are free of distortion or damage to threads.
- ☐ 6. Verify that each helmet and breastplate combination has four copper washers and twelve wing nuts. (4 wing nuts should be flanged).
- ☐ 7. Check serial numbers on the breastplate brales (straps) to insure that the proper brales are matched to a corresponding breastplate.
- ☐ 8. Check the operation of the air non-return valve (smoke test).
- ☐ 9. Check the packing on the air control valve. Verify presence of the cotter key.
- ☐ 10. Check the freedom of movement of the spitcock and verify that the nut is loose but not coming off.
- ☐ 11. Check the freedom of movement of both the handwheel and chin-button on the air exhaust valve.
- ☐ 12. Check the diving dress for wear or tears. Pay particular attention to the rubber collar gasket, bib, and cuffs.
- ☐ 13. Check leather, weights, and grommets on the weighted belt for wear or tearing. Pay particular attention to the jockstrap.
- ☐ 14. Check that helmet cushion or suitable padding is available for placement on diver's shoulders before breastplate is attached.

☐ **D. Lightweight Diving Outfit (Standard Mask)**

- ☐ 1. Check the lightweight dry dress for rips or excessive wear.
- ☐ 2. Check the lightweight diving belt for wear.
- ☐ 3. Check mask for general appearance or discrepancies in frame and seal. Check mask straps.
- ☐ 4. Check mask air non-return valve (smoke test).

☐ **E. Lightweight Diving Outfit (Diver's Mask USN Mk I)**

- ☐ 1. Check wet suit for tears or excessive wear.
- ☐ 2. Check faceplate and seal on the Mk I mask.
- ☐ 3. Check that face seal and oral-nasal mask are properly attached to the main mask body.
- ☐ 4. Check that all metal components are properly secured to the fiberglass body.
- ☐ 5. Inspect the mask for loose mounting bolts or excessive dents or damage.
- ☐ 6. Check that the nose clearing device slides in and out easily.
- ☐ 7. Check mask straps for wear. Gage the "bail-out" bottle.
- ☐ 8. Check flippers, weight belt and other accessory equipment according to SCUBA equipment checklists in Chapter Five.

☐ **F. General Equipment**

- ☐ 1. Check that all needed accessory equipment, tools, lights, special systems, spares, etc. are on scene and in working order. In testing lights, all tests should be conducted with lights submerged in water and extinguished before the removal to prevent overheating and failure.
- ☐ 2. Erect the diving stage or attach the diving ladder. In the case of the stage, be careful to insure that the shackle connecting the stage line is securely fastened **with the shackle pin seized with the wire to prevent opening.** Secure the air-hose bulwark roller in place.

☐ **G. Preparing the Air Supply**

- ☐ 1. Check that a primary and suitable back-up supply is available with a capacity in terms of **purity, volume,** and **supply pressure** to completely service **all** divers and accessory equipment throughout all phases of the planned operation.
- ☐ 2. Determine that proper personnel are available to operate and stand watch on the air supply.
- ☐ 3. 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 the appropriate operating and service manuals are on hand.
  - ☐ c. Check maintenance and repair logs to insure the suitability of the compressor (both primary or back-up) to support the operation.
  - ☐ d. Verify that all compressor controls are properly marked and any remote valving is tagged-off with "Diver's Air Supply-Do Not Touch" signs.
  - ☐ e. Make sure that the compressor is secure in the diving craft and will not be subject to operating angles that will exceed 15 degrees.
  - ☐ f. Verify that the oil in the compressor is of a type that is

proper for the particular compressor and is not petroleum-based. Check that the compressor oil does not overflow the "Fill" mark or contamination of the air supply could result from fumes or oil mist.

- ☐ g. Check that the compressor exhaust is vented away from work areas and, specifically, does not foul the compressor intake.
- ☐ h. Check that the compressor intake is obtaining a free and pure suction without contamination. Use pipe to lead intake to free suction is necessary.
- ☐ i. Check that compressors are not covered during operation.
- ☐ j. Check all filters, cleaners, and oil separators for cleanliness.
- ☐ k. Bleed off all condensed moisture from filters and the bottom of volume tanks (accumulators). All manifold drain plugs should be checked.
- ☐ l. Check that all petcocks are closed.
- ☐ m. Check that all belt-guards are properly in place on drive units.
- ☐ n. Check all pressure-release valves, check valves, and automatic unloaders. Make sure that the wing nut on the unloader is in the compressing position.
- ☐ o. Verify that all supply hoses running to and from the 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 even severed by machinery or other activities.

☐ **H. Activate the Air Supply**

☐ **1. Compressors—**

- ☐ a. Make sure that all run-up and warm-up procedures are completely followed.
- ☐ b. Check all petcocks, filler valves, filler caps, overflow points, bleed valves, and drain-plugs for leakage or malfunction of any kind.
- ☐ c. Soap-test all valves and connections.
- ☐ d. Verify that there is a pressure gage on the air receiver and that it is functioning properly, and that the compressor is meeting its delivery requirements.
- ☐ e. Check that the air supply is not being delivered below purity standards (smell, taste), or in excess of 95°F.
- ☐ f. In all cases where compressors are used as a back-up, either to a shipboard system, cylinder bank, or another compressor—the back-up compressor will be **kept running** throughout the diving operation.

☐ **2. Cylinders—**

- ☐ a. Gage all cylinders for proper safety.
- ☐ b. Verify the availability and suitability of the reserve cylinders.
- ☐ c. Check all manifolding and valving for operation.
- ☐ d. Activate and check delivery.

☐ **3.** For **all** supply systems, double check "Do Not Touch" tags.

☐ **I. Air Hoses**

☐ 1. Check that all hoses have a clear lead and are not subject to heating or damage.

☐ 2. Check that no hose length used exceeds five years in age from the date of manufacture (age is marked on each length 4″ from the end). Air hose used on ASR (Auxiliary Submarine Rescue) vessels may not exceed 3 years of age in any length.

☐ 3. If possible, make sure that the hose (or any length) has not been used in burst test program. No length involved in such a program may be part of an operational hose.

☐ 4. Check that hoses are free of moisture, packing material, or chalk.

☐ 5. Soap test hose connections after they have been hooked up to the air supply and pressurized.

☐ 6. Check that the newest (or best) hose length is the section nearest the surface, since that is the region in which the hose will be subjected to the greatest pressure change.

☐ 7. Check that all tie-offs, and the canvas chaffing over the first length of hose are in proper condition.

☐ 8. If possible, check gaskets at hose-length connections.

☐ **J. Test of Equipment with Activated Air Supply**

☐ 1. Hook-up all air hoses to helmets, masks, chambers, and make connections between back-up supply and primary supply manifold.

☐ 2. Verify flow to helmets and masks.

☐ 3. Check all exhaust and air control valves.

☐ 4. Hook up and test all communications.

☐ 5. Check air flow from both primary and back-up supplies to chamber.

☐ 6. Detach all hoses except that leading to chamber. Make sure chamber supply is completely shut off and no air is leaking to chamber, depleting the air supply.

☐ **K. Recompression Chamber Checkout (Pre-dive only)**

☐ 1. Check that the chamber is completely free and clear of all combustible materials. This includes paint cans, refuse, matches, lighters, etc.

☐ 2. Check primary and back-up air supply to chamber as well as all pressure gages.

☐ 3. Check that the chamber is free of all odors or other contaminants.

☐ 4. Check the chamber oxygen supply, and that suitable numbers of oxygen masks are rigged for at least two divers, one tender, and one medical assistant.

☐ 5. Verify the presence of a sanitary bucket in the chamber in case of sickness.

☐ 6. Verify that the medical kit is completely outfitted and in the chamber

☐ 7. Check all doors and seals.

☐ 8. Verify that all chamber electrical fittings are fitted with armoured cable and special lighting fixtures and bulbs. All switches should be on the outside of the chamber.

☐ **L. Final Preparations**

☐ 1. Verify that all necessary records, logs, and timesheets are on the diving station.

☐ 2. Check that appropriate decompression tables are readily at hand.

☐ 3. Verify that all air supply systems have a volume tank or accumulator installed in the air supply line between the supply source and the diver's hose connection. An oil separator must be installed between the tank and the connection.

☐ 4. Place the dressing bench in position, make sure that the diver will not have a long way to travel to reach the diving ladder or stage.

APPENDIX L

PRESSURE TEST FOR USN RECOMPRESSION CHAMBERS

A pressure test must be conducted on every USN recompression chamber—

1. When initially installed.
2. When moved and re-installed.
3. At five-year intervals at a given location.

The test procedures are as follows—

1. Pressurize the innermost lock to 100 feet (45 psig). Using soapy water or an equivalent, leak-test all shell penetration fittings, viewports, hatch seals, hatch dogs (where applicable), valve connections, pipe joints and shell weldments.
2. Mark all leaks. Depressurize the lock and adjust, repair or replace components as necessary to eliminate the leaks.
   - **a** Viewport Leaks—Remove the viewport gasket (replace if necessary), wipe clean and lubricate with an approved lubricant (re. NAVSHIPS Note 9230).

     When re-installing the viewport, take up the retaining ring bolts until the gasket just compresses evenly about the viewport. Do not overcompress the gasket.
   - **b** Weldment Leaks—Repair in accordance with applicable requirements of MIL-STD-278 for class A-2 pressure vessels. Stress relief heat treatment is not required. Hydrostatically test as per special instructions which may be obtained from Navy Experimental Diving Unit.
3. Repeat steps 1 and 2 until all the leaks have been eliminated.
4. Pressurize the lock to the chamber's maximum design pressure (not hydrostatic pressure) and hold at that pressure for 5 minutes.
5. Depressurize the lock to 165 feet (73.4 psig). Hold at 165 feet for 1 hour. If the pressure drops below 145 feet (65 psig), locate and mark the leaks. Depressurize the chamber and repair the leaks in accordance with Step 2 above and repeat this procedure until final pressure is at least 145 feet.
6. Repeat steps 1 through 5 leaving the inner door open and outer door closed. Leak test only those portions of the chamber not previously tested.

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