RESEARCH DIVER'S MANUAL

REVISED AND EXPANDED EDITION

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I INTRODUCTION

1.0 Introduction

1.1 Overview

During the last two decades, diving with self-contained underwater breathing apparatus (SCUBA) has become an important method of scientific investigation. The underwater scientist (Figure 1-1) does not have to depend on conventional surface sampling techniques and "educated guesses" for shallow-water studies. He can work directly in the underwater environment to observe, sample, photograph, and make complete field studies in much the same manner as his dry-land colleagues. Working underwater, the scientist may record evidence which might be completely misused using conventional surface sampling and remote recording techniques.

The underwater scientist does, however, have many disadvantages compared to his dry-land counterpart. He is limited in depth and duration by physiological and physical factors. Weather conditions and underwater visibility are also important factors affecting underwater work. For the nondiver, Tanner (1959) explains his impression of working underwater:

> It is like doing ordinary dry-land fieldwork, on a cold January night, without a moon, during a dust storm, by the light of a flashlight of variable power. The vehicle in the exploration would have to be a helicopter, restricted to flying largely out of sight of the land surface. It lowers the geologist (by rope ladder, perhaps) to the ground, at each sampling location. He can only see those materials within the range of his flashlight beam. This might be as much as 60 or 70 feet, or as little as six or seven inches. In the latter instance he would have to work with his face to the ground: fortunately that is a convenient position for a diver.

Certainly all research dives are not as difficult as one might conclude from the above explanation. However, physiologically man possesses few natural adaptations for existing in a liquid medium and for the conservation of body heat.

Despite the disadvantages and limitations, the research diver quickly learns to adapt himself to the underwater environment. Recent developments in diving suits and life-support equipment have increased the diver's underwater capabilities. Mixed gases,

Figure 1-1. Research Diver Equipped with Surface-Supplied Free-Flow/Demand Mask and Variable-Volume Suit Installing a Current Meter for Study of Water Circulation in Grand Traverse Bay (Photo by R. Johnson)

saturation diving, and the use of underwater habitats offer solutions to the depth and duration limitations for those fortunate enough to have the proper equipment. The application of modern surface-supplied diving techniques and equipment, compared to conventional open-circuit SCUBA, has been shown to increase the efficiency of research diving operations at The University of Michigan by a factor of four for most underwater scientific projects.

Underwater work is difficult, time-consuming, and expensive. Generally, diving investigations are used to supplement, verify, or complete data acquired by other methods of study. For example, research divers may be required to identify bottom features encountered during bathymetric, sub-bottom seismic, or sidescanning sonar surveys. A geological investigation of an underwater construction site made totally by divers would probably be considered inadequate for determining details of the area unless other methods of investigation were also used. However, basic field research on fish behavior might be completely undertaken using diving techniques. Regardless of the project or the role that the diver plays in a study, it is the general consensus of those scientists who participate and benefit from underwater studies that research diving techniques are of considerable importance and, in some instances, invaluable to the study of our lakes and oceans.

The basic principles of air diving with SCUBA and surface-supplied equipment are discussed in this technical report. Emphasis is primarily on diving in the Great Lakes. Forthcoming chapters of this report will cover such topics as ocean diving, biological and geological research techniques, underwater photography, light salvage, underwater research procedures, mixed gases, and other specialized diving techniques.

1.2 History of Diving

The accumulation of seashell artifacts at prehistoric living cites possibly indicates that food was taken from the sea by divers long before references in recorded history. The earliest records are of Cretan sponge divers (3000 BC) and diving for oyster pearls in China (2200 BC). Military divers were used during the Trojan War (ca. 1194 BC). Reference to military diving activities is made by Herodotus (5th century BC) and in Homer's *Iliad* (pre-700 BC). Alexander the Great deployed frogmen against the defenses of Tyre (333 BC) and was supposed to have descended in a diving bell himself. Records indicate paid salvors and diving regulatory laws in the 3rd century, BC.

Aristotle (4th century BC) writes of the *diving bell.* Prior to this time all diving was probably done by breathholding to depths not exceeding much over 100 ft. The diving bell was the dominant diving apparatus for the next 22 centuries, until about 1800. In the late 1600s the bell was refined and in 1691 a sizable and sophisticated bell was patented by Edmond Halley. This bell was ventilated by lowering barrels of fresh air, and dives were made to 60 ft for 1.5 hr; divers made breathholding excursions from the bell.

By 1770 the elementary hand-operated air compressor provided the next major advancement in diving. This enabled LeHavre (1774) to develop a moderately successful helmet-hose diving apparatus. Surface-supplied compressed air diving developed as the prevalent diving technique by 1800 and was to maintain a virtually unchallenged position until the mid-1950s. A boosting factor to diving in the 1800s was the salvage of HMS *Royal George*. For this operation Augustus Siebe developed and perfected the diving helmet and "closed dress" in 1837. The Siebe helmet and "closed dress" were the primary diving apparatus for the working diver from 1837 to the 1960s. The present US Navy Mark V Deep-Sea Diving Outfit is only a modification of the 1837 Siebe outfit.

Progress in diving, from 1837 to present, was dependent on two factors: improvement of the air compressor and the study of hyperbaric physiology. The compressor improved rapidly during and following the industrial revolution; however, the study of diving physiology was slow to progress. Paul Bert, in 1878, started to untangle the complexities of nitrogen absorption and elimination, or the "bends." The first recompression chamber for treatment of bends was installed to support the cassion workers during construction of the first Hudson River Tunnel in New York (1893). In 1907, based much on Paul Bert's work, John S. Haldane published the first decompression tables for divers.

However, the development of SCUBA did not begin with Cousteau. In 1680, Borelli developed a SCUBA based on the theory that the diver's hot, exhaled breath could be rejuvenated by cooling and condensing. Needless to say, this unit was not successful; however, this represents a movement toward "freeing" the diver. Borelli also experimented with the "fin" and bouyancy-compensating devices. In 1835, Condert published the design of a free-flow SCUBA, which consisted of a helmet, flexible dress, and a compressed-air reservoir fitted around the diver's waist. This was to have significant influence on the design of future diving apparatus. Rouquayrol (1865) developed a "demand" regulator system. Although this unit was basically surface-supplied by a hose, it also had significant influence on the development of SCUBA. In 1878, Fleuss and Davis designed the closed-circuit oxygen SCUBA, which utilized a chemical carbon dioxide absorbent. This was the beginning of a long list of closed-circuit oxygen SCUBA with the eventual development of the semiclosed circuit, mixed-gas SCUBA by Lambertsen. Yves le Prieur, in 1924, introduced a manual, valved, self-contained, compressed-air breathing apparatus. In 1942, Cousteau and Gagnan developed the demand-type SCUBA, which is the basic compressed-air SCUBA used throughout the world today.

Sport diving and spearfishing were being practiced in many European countries during the 1920s and were introduced into the United States in the late 1920s. It wasn't until the early 1950s, with the ready availability of compressed-air SCUBA, that the popularity of sport diving started to accelerate to its present status. Factors contributing to the growth of sport diving include availability, improvement, and simplification of diving apparatus; an increased number of training programs; publication of the exploits of naval diving groups such as those of the Underwater Demolition Team (UDT) and SEAL Team; an increased layman's interest in ecology, oceanography, and related disciplines; and the general increase in need for leisure time and recreational activities.

According to Dugan (1956), the first recorded scientific dives were made by H. Milne-Edward (Sicily) in 1844. Over the years, many dives of a scientific nature have probably been made by breathholding and with helmet or bell-type diving apparatus. Engineering survey dives were also made in the 1800s. Geologists, during the late 1940s, used deep-sea and shallow-water surface-supplied diving apparatus for limited underwater observations. However, it wasn't until 1949 that modern scientific diving had its true beginning in the United States. Conrad Limbaugh introduced self-contained scientific diving at Scripps Institution of Oceanography. Since 1949, Scripps and the Navy Undersea Warfare Center (formally, US Navy Electronics Laboratory) at LaJolla, California, have had the largest and most active group of diving scientists in the world. Currently, nearly all research groups studying the freshwater and marine environment utilize divers to various degrees.

The beginning of the US Navy diving program is not actually known; however, official records indicate that George Stillson began developing the Navy's program in about 1912. The F-4 submarine disaster of 1915, which somewhat paralleled the more recent *Thresher* incident in terms of government and public reaction, apparently stimulated interest in diving. The first US Navy diving school was opened in 1915, and the Navy's famous Experimental Diving Unit was originated in 1927. Navy helium-oxygen diving experiments began in the 1930s and were used extensively in the salvage of the submarine *Squalus* (1939). During World War II, the great potential of military diving became evident. The famous USN Underwater Demolition Team had its beginning in 1943. The US Navy's diving program is ranked "first" in the world by most authorities.

Experimentation in living in a hyperbaric environment began in the early 1960s. The concept of saturation diving and living in underwater habitats was introduced by G. Bond, a US Navy submarine medical officer. In 1964, the first US underwater living experiment, SEALAB I, was conducted off Bermuda at a depth of 192 ft. SEALAB II and other projects followed as part of the continuous Man-in-the-Sea Program. Concurrently, Cousteau (of France) conducted the CONSHELF series of underwater living and work programs with a successful 28-day/330-ft submergence. More recently, the TEKTITE Program has provided an opportunity for scientists to utilize saturation diving techniques.*

Man is now pushing to greater depths and staying for longer durations. Working dives have been made to depths exceeding 500 ft and experimental chamber dives have tested man's ability to function in excess of 1700 ft. New self-contained closed-circuit mixed-gas breathing apparatus is capable of sustaining a diver at depths beyond 1000 ft for up to 6 hr. The increasing demand for the working diver in the oil industry and offshore construction has opened a new era of diving. During the last decade, the diving industry has made tremendous advancements via "commercial," rather than "military," influences. The immediate future holds many advancements in diving apparatus, techniques, and physiology which will influence the expansion of research, commercial, sport, and military diving activities.

1.3 Diver Training

All research divers must successfully complete a diver training program prior to participating in underwater research activities. Generally, initial training is acquired in a basic skin and SCUBA

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*For further information on the history of diving, consult Dugan (1956, 1965), Searle (1966), Davis (1962), Fane and Moore (1956), Cousteau (1953), and US Navy (1970).

diving course conducted under the auspices of an instructor certified by the National Association of Underwater Instructors, Young Men's Christian Association, Professional Association of Diving Instructors, or equivalent organizations. Such a course includes training in basic skin and SCUBA diving skills, emergency procedures for open-circuit SCUBA, equipment use and maintenance, and introduction to the underwater environment, and basic diving theory.

Most of these courses, though adequate for sport-diving enthusiasts, are inadequate for training research personnel or "working" divers. Generally, the basic sport-diving course must be supplemented with more emphasis on equipment, procedures, advanced techniques, and supervised open-water diving. A few universities and governmental agencies conduct specialized research diver training programs. Advanced training in research techniques and surface-supplied diving is recommended. Basic and advanced research diver course outlines are included in Appendix B. Diver training qualification tests given by Somers (1971) are also included in Appendix B of this manual.

1.4 MEDICAL QUALIFICATIONS

Applicants for diver training and all active divers are required to pass an annual physical examination. The medical requirements for diving are summarized as follows by Lanphier (1957):

> One of the primary considerations is that diving involves heavy exertion. Even if a man does not intend to engage in spearfishing or other activities which are obviously demanding, he will sooner or later find himself in situations which tax his strength and endurance. Even the best breathing apparatus increases the work of breathing, and this adds to the problem of exertion underwater.
>
> Lifting and carrying the heavy equipment on dry land is also hard work. The necessity for freedom from cardiovascular and respiratory disease is evident. Individuals who are sound but sedentary should be encouraged to improve their exercise tolerance gradually by other means before taking up diving. The influence of exertion on conditions such as diabetes should be considered carefully. It is not reasonable to apply a fixed age limit to sport divers, but men over 40 deserve special scrutiny.

An absolute physical requirement for diving is the ability of the middle ear and sinuses to equalize pressure changes. The Navy applies a standard "pressure test" in a recompression chamber to assess this ability since usual methods of examination have insufficient predictive value unless obvious pathology is present. However, even going to the bottom of a swimming pool will generally tell a man whether his Eustachian tubes and sinus ostia will transmit air readily or not. In the case of middle ear equalization, part of the problem is learning the technique of "popping your ears." Presence of otitus or sinusitis is a definite contraindication for diving, even in a man who can normally equalize pressure. A history of disorders of this sort suggests that diving is unwise; but as in the case of frequent colds or allergic rhinitis, prohibition of diving is not invariably justified. Here, much depends on the individual's common sense and ability to forego diving if he has trouble. A perforated tympanic membrane should rule out diving because of the near certainty of water entering the middle ear. The use of ear plugs presents no solution to any of these problems and is, in fact, strongly contraindicated.

Any organic neurological disorder, or a history of epileptic episodes or losses of consciousness from any cause, makes diving highly inadvisable. A more difficult problem for the physician to evaluate and handle adroitly arises in the psychiatric area. The motivation and general attitude of some aspirants make safe diving unlikely from the outset; and those individuals who tend to panic in emergencies may well find occasion for doing so in diving. Recklessness or emotional instability in a diver is a serious liability for his companions as well as for himself. Claustrophobic tendencies are clearly incompatible with diving.

Further information regarding the diver's physical examination and qualifications is available in US Navy (1970), Miles (1966), and Dueker (1970). A medical examination form is included in Appendix A.

1.5 Physical Fitness

Flexibility, strength, and endurance are necessary for underwater swimming and diving. Good physical condition may prove to be the most important aspect of diving safety. The physically fit individual is able to withstand fatigue for longer periods and is better equipped to tolerate physical stress. Diving, particularly for novices, places severe stress on the entire body, especially the cardiovascular and respiratory systems. Anxiety, lack of skill (inefficiency), nonconditioned heart, hyperventilation, overweight, equipment restrictions, breathing resistance, and cold water are among the factors which cause increased heart rate and the onset of fatigue. As a general rule, average participation in diving activities is not sufficient in itself to develop and maintain a high level of physical fitness. Diving *must* be supplemented by a regular exercise program. This is especially true for persons who do not dive on a regular basis. Persons who participate only on a seasonal basis should exercise regularly when not diving, or at least initiate a conditioning program six to eight weeks prior to the diving season. Jogging is an excellent conditioner for divers. Consult Cooper (1970), President's Council on Physical Fitness (1965), or other publications recommended by your physician or instructor for exercise programs.

1.5.1 Smoking and Diving

Mounting medical evidence has not only proven that smoking can and does cause lung cancer but it has also been linked with such conditions as hardening of the arteries, pulmonary emphysema, cholesterol buildup, and heart attacks. From a diver's viewpoint, smoking is probably the most common single cause of local intrapulomonary obstruction. Tobacco smoke irritants cause chronic inflammatory changes in the bronchial lining and increase the amount of bronchial mucous in the airways. These conditions could result in airflow obstructions which may induce an air embolism during ascent. Smoking heavily may impair one's ability to utilize oxygen by at least 15 percent, since carbon monoxide combines with hemoglobin, making it incapable of transporting oxygen. Smoking and the diver is discussed further by Tzimoulis (1971). *Divers should* not *smoke!*

1.5.2. Drugs, Alcohol, and Diving

Any form of stimulant or depressant should be avoided prior to and during diving operations. Although evidence of adverse long-term effects of smoking marijuana are considered inconclusive by some individuals, the smoking itself still produces some of the complications described in the previous section. In addition, this drug can produce significant temporary adverse effects on the diver's mental processes, motor coordination, physical stamina, and tolerance to cold. In warm water the diver may become ultra-relaxed, sleepy, unaware, lazy, and his work ability may be reduced significantly. Regardless of the effect, it is unlikely that the diver will be able to respond properly, if at all, in the face of panic or underwater emergency.

Consumption of alcoholic beverages prior to and during diving operations must also be avoided. The immediately apparent effects are mental disorientation, impaired physical coordination, vertigo, poor judgment, and general physical weakness. Physiologically, alcohol also produces a diuretic effect, thereby causing dehydration of the body, which, in turn, affects the circulatory functions. The implications in decompression sickness are discussed later.

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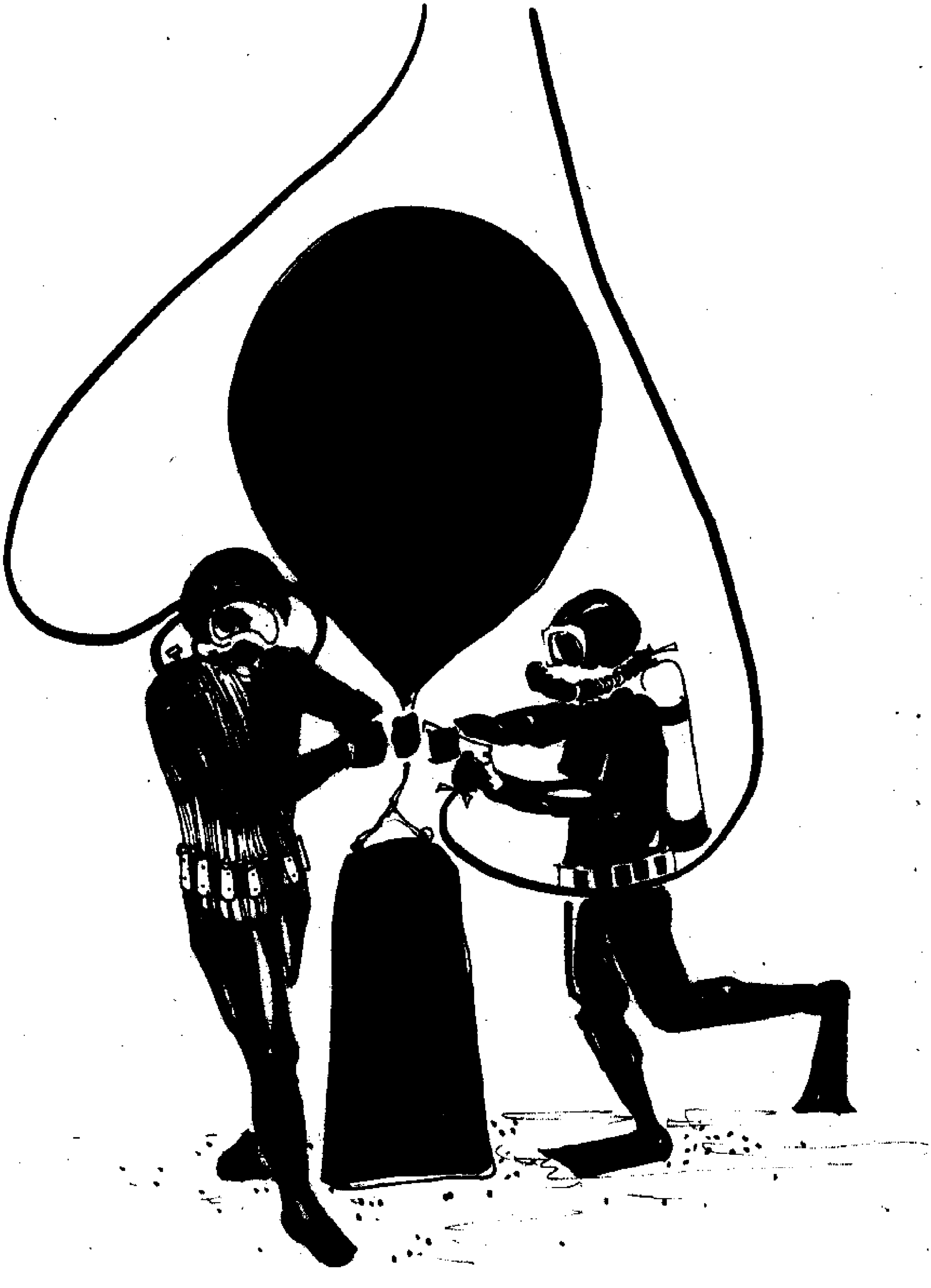

2 DIVING PHYSICS

2.0 Diving Physics

Nearly all new experiences, both pleasant and unpleasant, encountered in diving stem directly from the great differences in physical properties and characteristics which exist between the gaseous and liquid media. Some apparent differences include

- water has an increased density and viscosity,
- optical and acoustical properties differ,
- water has a higher degree of heat conductivity than air,
- gases breathed under increased pressure have varient physiological effects.

In order to understand the basic principles of diving, the diver must be familiar with certain aspects of physics which deal with pressure and density relative to liquids and gases.

2.1 PRESSURE

Pressure is the amount of force applied per unit area. In diving, pressure units commonly used are millimeters of mercury (mm Hg), pounds per square inch (lb/in^2 or psi), and atmospheres (atm). One atmosphere is the amount of pressure or force exerted by the earth's atmosphere at sea level and is equal to 14.7 lb/in^2 or 760 mm Hg. Terms frequently used when referring to pressure include gauge pressure, absolute pressure, and ambient pressure. *Gauge pressure* refers to the difference between the pressure being measured and the atmospheric pressure. Most gauges are calibrated to read "zero" at normal atmospheric pressure. *Absolute pressure* is gauge pressure plus atmospheric pressure (14.7 lb/in^2) or total pressure being exerted. *Ambient pressure* refers to absolute pressure surrounding or encompassing an object.

2.2 WATER

Water, in its purest form, is a colorless, odorless, tasteless, and transparent liquid. Taste and color are due to the presence of substances dissolved or suspended in the water. Pure water weighs 62.4 lb/ft^3 (STP), while sea water weighs approximately 64 lb/ft^3, depending on the amount of total dissolved solids. For all practical purposes, within the normal range of diving, water can be considered as incompressible and density variations due to temperature changes insignificant. Consequently, the pressure exerted by water will be directly proportional to the depth. For every 33 ft in sea water (34 ft in fresh water) the diver descends, there is a pressure increase of 1 atm or 14.7 lb/in^2; pressure increases .445 lb/in^2 per foot of descent.

An object placed in water will sink or float depending on the density and volume of the object. *Archimede's principle* states that any object wholly or partially immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced. For example, a fully equipped diver weighing 192 lb may displace 3.16 ft^3 or 202 lb of sea water. Consequently, he is considered to have 10 lb of positive buoyancy. If the same diver was outfitted with a 20-lb weight belt, he would be 10 lb negatively buoyant. Neutral buoyancy, or a state of hydrostatic balance, is achieved when the weight of the water displaced equals the weight of the object when totally submerged. Sea water increases an individual's buoyancy by approximately one-thirtieth his body weight over what it is in fresh water.

Water conducts heat more rapidly than any other liquid. In water below 70^o F, body heat is lost faster than it can be replenished.

2.3 Air

This manual deals primarily with diving using air as a breathing medium. Air is composed of nitrogen (78.1 percent), oxygen (20.9 percent), carbon dioxide (0.033 percent), and various inert and rare or trace gases. It may also contain water vapor and suspended and dissolved solids.

Nitrogen, the main component of air, is colorless, odorless, tasteless, and inert (in its free state). Under increased pressures, it is selectively soluble in various body tissues and acts as an intoxicant or anesthetic on the central nervous system (CNS).

Oxygen, the only gas capable of supporting life, is colorless, odorless, and tasteless in its free state. Under high pressures, oxygen has toxic effects on the body.

Carbon dioxide, a natural waste product of metabolism, is colorless and tasteless (in normal concentration). It is the principal respiratory process stimulant. High concentrations are toxic to the human and will produce unconsciousness with subsequent death (higher concentrations).

Other gases important to the diver are carbon monoxide and helium. *Carbon monoxide* is highly poisonous, and all possible measures must be taken to prevent its contamination of the diver's air supply. It is the product of incomplete combustion of fossil fuels. *Helium* is colorless, odorless, tasteless, inert, lightweight, nontoxic, and nonexplosive. During the last two decades, helium has become the major inert gas substituted for nitrogen in deep-diving breathing media. Narcotic effects of helium are relatively insufficient (to 800 ft) and breathing resistance due to lower density is reduced. However, helium does conduct heat about five times as rapidly as air.

In comparison to a liquid or solid, air, as any gas, has a very low density, is compressible, and its behavior is governed by simpler laws of physics. Air weighs only about 0.081 lb/ft^3. The temperature, pressure, and volume relationships are more conveniently expressed in terms of an imaginary substance called an "ideal gas."

If the temperature of a fixed mass of gas is kept constant, the relationship between the volume and pressure will vary in such a way that the product of the pressure and volume will remain essentially constant. Mathematically,

$$pV = \text{constant},$$

where p is pressure (absolute) and V is volume. The temperature and mass are constant. Thus, at a constant temperature and mass the volume of a gas is inversely proportional to the pressure exerted on that gas,

$$p \propto \frac{1}{V}.$$

Therefore, when the pressure is doubled, the volume is reduced to one-half of the original volume. This relationship is known as *Boyle's law* and is graphically illustrated in Figure 2-1. Two different states of a gas at the same temperature may be denoted by subscripts 1 and 2 and Boyle's law may also be written

$$p_1V_1 = p_2V_2.$$

Charles's law states that if the pressure of a fixed mass of gas is kept constant, the volume of the gas will vary directly with the absolute temperature. By combining Boyle's and Charles's laws, the pressure, temperature, and volume relationships of an ideal gas can be expressed as

$$\frac{pV}{T} = \text{constant}.$$

Two states of the gas may be denoted with subscripts,

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}.$$

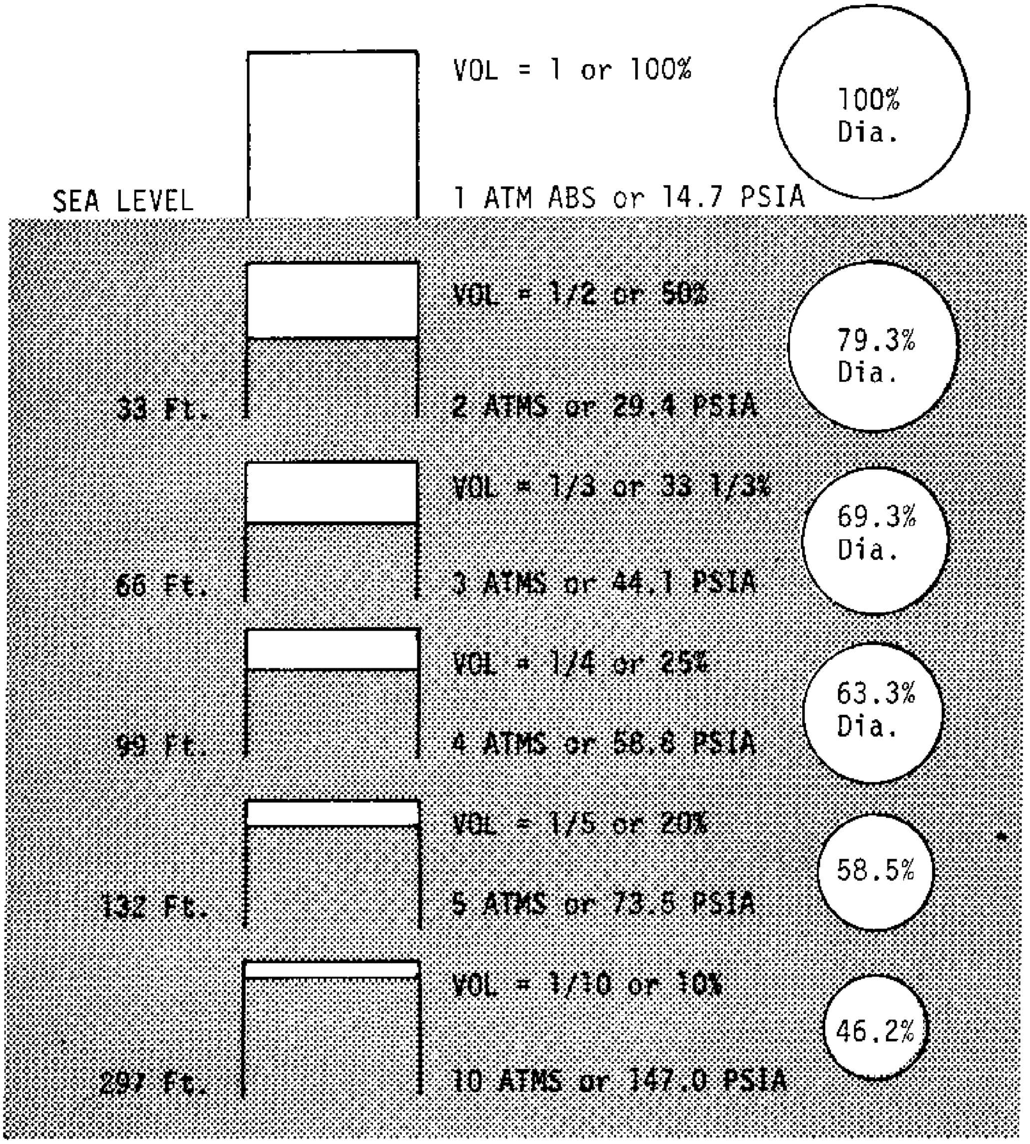

Figure 2-1. The Relationship Between Depth, Pressure, and Volume

In diving, one generally works with a mixture of gases rather than a single pure gas. The concept of partial pressure is explained by *Dalton's law,* which states that the total pressure exerted by a mixture of gases is the sum of the pressures that would be exerted by each gas if it were present and occupied the total volume. Partial pressure computations are useful for understanding diving physiology and necessary for mixed-gas diving. The partial pressure (pX) of a given gas in a mixture may be calculated by the formula,

$$pX = P_t X_{\%},$$

where P_t is the total pressure of the gas mixture (absolute) and $X_{\%}$ is the percent of gas X by volume in the mixture. Hence, the partial pressure of oxygen in the atmosphere at sea level is

$$pO_2 = 14.7\ (.21) \text{ or } 3.1\ \text{lb/in}^2.$$

Gas is soluble in a liquid. Gas absorption is governed by *Henry's law,* which states that the amount of a gas that will be dissolved in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas. The term "amount" refers to number of molecules or mass of the gas. When gas is in solution, its actual volume is negligible and there is no volumetric increase in the amount of liquid. Henry's law simply expresses the effect of partial pressure on the amount of gas that will dissolve in a liquid. Solubility is also dependent on the type of liquid and temperature. For example, the solubility of nitrogen in oil or fat is about five times its solubility in water at the same pressure. The lower the temperature, the higher the solubility. This explains why a warm bottle of carbonated beverage forms bubbles more actively than does a cold one.

Gas diffusion refers to the intermingling of gas molecules. In diving, Henry's and Dalton's laws are considered when dealing with the diffusion of gas in the human body under pressure. The difference between the partial pressure (or tension) of a gas inside of a liquid (or container) and its outside partial pressure will cause the gas to diffuse in or out of the liquid and control the rate of diffusion. This pressure differential is frequently called the gradient. If a gas-free liquid is exposed to a gas, the inward gradient is high and the rate at which gas molecules will migrate into the liquid is high. As the gas tension in the liquid increases, the rate of diffusion decreases and eventually reaches an equilibirum, where the gas tensions in the liquid and outside the liquid are equal. The liquid is then considered saturated for a given pressure and gas. The subjects of gas solubility and diffusion are important in the study of decompression sickness and nitrogen narcosis.

2.4 Light and Vision Underwater

The penetration of light is an important factor for divers, particularly when taking underwater ambient light photographs. The luminous energy of sunlight diminishes underwater with increased depth. Basically, in clear water the luminous energy (or ambient light) is reduced to one-fourth surface value at 16 ft, one-eighth surface value at 50 ft, and one-thirteenth surface value at 130 ft. Solar light probably does not penetrate beyond 1650 ft even under the most ideal conditions of transparency. Many factors control light penetration. When a light ray enters the water, it is reflected, refracted, transformed to heat, absorbed, and diffused by the water and materials in the water. The colors of the solar spectrum are absorbed, with practically all red colors gone at a depth of 30 ft and only blues and greens visible at 100 ft.

Underwater refraction is never greater than 48.5 degrees, the critical angle of refraction. This corresponds to a grazing incident ray in air (at sunset and sunrise). A ray of light directed upward (underwater) at an angle greater than 48.5 degrees is totally reflected back into the water instead of being partially refracted into the air. This makes the surface appear as a mirror when the diver is in the proper position. Due to the refraction of light rays passing from water to air, objects viewed underwater through a face plate appear one-fourth closer and one-fourth larger. Light travels at three-fourths the speed in water that it does in air.

2.5 Propagation of Sound

The average speed of sound underwater is about 4900 ft/sec, compared to a speed of less than 1100 ft/sec in air. Various types of sonic and ultrasonic equipment are used for depth sounding, location of submerged objects, and wireless communication. Large sonar transponders (on military vessels) and underwater explosions are a serious hazard to divers.

2.6 Additional Information

This presentation has been only a brief review of the basic physical principles necessary for the study of diving theory. For additional information on diving physics refer to US Navy (1970). Diving instructor candidates must thoroughly understand the various aspects of diving physics as given in that document.

2.7 REFERENCES

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3 PHYSIOLOGICAL & MEDICAL ASPECTS OF DIVING

3.0 Physiological & Medical Aspects of Diving

3.1 Introduction

The human body is designed to function in a gaseous atmosphere of approximately 20 percent oxygen and 80 percent nitrogen at a pressure of about 15 lb/in^2. Significantly decreasing or increasing the pressure exerted on the body or changing the partial pressure of the breathing medium can induce radical physiological changes. Low-level gas contaminants such as carbon monoxide and carbon dioxide have serious implications at the higher pressures encountered while diving and may cause unconsciousness, with subsequent drowning. Prolonged breathholding while subjecting the body to significant pressure changes, as during skin diving, can result in unconsciousness without significant signs to indicate the onset of complications. Subsequently, the diver may drown. The human's normal atmosphere, oxygen and nitrogen, produces both toxic and narcotic effects when breathed at high pressure. In addition, the inert gas is absorbed during pressurization and must be eliminated from the body at a prescribed rate to avoid complications.

One must also consider the direct physical effects of pressure. The human body has been exposed to pressure equivalents exceeding 1700 ft during experimental chamber dives, without apparent residual damage. Exactly how much pressure the human body can endure is still unknown. The body contains several rigid or semirigid gas-containing spaces (middle ear, paranasal sinuses, lungs and airways, and gastrointestinal tract), which, because of restricted openings, are subject to mechanical damage when pressure differentials exist between the internal space and the external environment.

The effects of high pressure on the human body and breathing media must be fully understood by the diver. If physiological reactions to high pressure are not recognized by the diver and properly controlled, injury or death may occur. For discussion purposes, the physiological and medical aspects of diving will be classified into the following categories:

- barotrauma,
- impairment of consciousness during breathhold diving,
- breathing media contamination,
- gas narcosis and toxicity,
- decompression.

3.2 Barotrauma

Living tissue can be exposed to relatively high pressures without damage or changes attributable to the pressure itself. Behnke (1944) remarks on man's tolerance to rapid and extreme alterations in barometric pressure "without physiologic effects" relative to diving to a maximum of 500 ft. Recently, Brauer (1968) suggested a physiological depth barrier, using the gas mixture tested so far, as a result of a series of experimental chamber dives reaching a maximum of 1189 ft. More recently, chamber dives have been successfully completed to more than 1700 ft. However, central nervous system (CNS) involvement appears to be the limiting factor, and not necessarily mechanical tissue damage. At pressures above 1000 atm, well beyond ordinary diving pressures, Fenn (1967) indicates coagulation of proteins, inactivation of enzymes, disintegration of red blood cells, and blood coagulation. At the present state of hyperbaric research, there is no definite answer to the question, "How much pressure can the human body tolerate?"

As stated previously, the human body contains several rigid or semirigid, air-containing spaces, which, because of restricted openings, are subject to mechanical damage when unequalized pressure differences exist. These air-containing structures of the body are the middle-ear spaces, the paranasal sinuses, the lungs and airways, and the gastrointestinal tract. With the exception of these air-containing spaces, the entire body consists of fluids and solids, which for all practical purposes within the limits of diving are incompressible. The middle ear and sinuses are lined with membranes containing blood vessels. As the external pressure being exerted on the body is changed, this pressure is transmitted via the blood vessels to the membrane lining of these air spaces. Unless the pressure in these spaces is equal to the ambient pressure, a pressure differential exists causing *barotrauma*, or pressure injury.

Reuter (1971) recommends a preventive approach to ear barotrauma which includes the use of a nasal spray, systemic decongestant, or middle ear ventilation by self-inflation. The use of the nasal spray oxymetazoline HCl (Afrin) 20 min prior to the dive is recommended. A systemic oral decongestant with or without an antihistamine may also be used 20 min prior to the dive. Pseudoephedrine HCl (Sudafed) is recommended for those who are made drowsy by antihistamine combinations.

3.2.1 Middle Ear Squeeze

The middle ear (Figure 3-1) is connected with the throat by the Eustachian tube, which functions to drain and ventilate the middle ear. When Eustachian tube blockage (mucus or congestion, tissue overgrowth, local inflamation and swelling) prevents pressure equalization in the middle ear, painful *aerotitis media*, or "middle ear squeeze," may occur, with possible tympanic perforation (rupture of the eardrum). The diver will experience discomfort and pain in the first few feet of descent. Further descent will re-

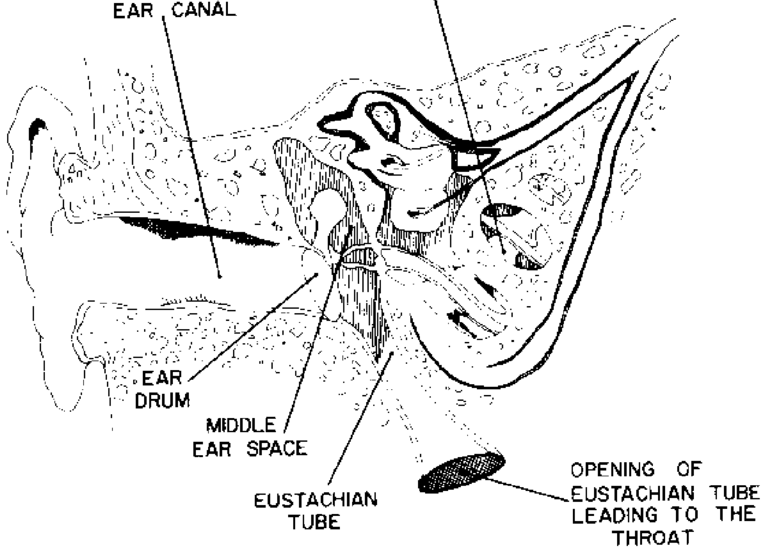

Figure 3-1. Anatomy of the Ear (Photo Courtesy of US Diver Co.)

sult in increasing pain, with stretching of the eardrum and dilation and eventual rupture of the blood vessels in both the tympanic membrane and the lining of the middle ear. Actual *rupture of the eardrum* may occur with a pressure differential of as little as .5 lb/in2, at a depth of about 10 ft (Lanphier, 1957). Generally a slight blockage of the Eustachian tube by mucus or swelling can be overcome by maneuvers for "clearing the ears" such as swallowing, yawning, or exhaling against closed mouth and nostrils (Valsalva maneuver). Variations in ability to ventilate the Eustachian tube may in some instances be an anatomical factor of the individual's tube size (Taylor, 1959).

The diver is cautioned to use the Valsalva maneuver with discretion. Increased intrathoracic pressure produced during the maneuver will result in hypotension in the normal individual. This is primarily due to impairment of venous return to the heart and the potential of the pulmonary stretch reflexes inducing certain cardiac arrhythmias. Duvoisin et al. (1962) suggest that the combination of these two influences is probably responsible for the syncope (fainting) that frequently occurs upon doing the Valsalva maneuver. Davison (1962) indicates that the Valsalva maneuver could result in a catastrophic outcome and further suggests that these factors led Armstrong (1961) to state that any prolonged Valsalva maneuver should be avoided during airplane flights (particularly by pilots). In fact, the cardiovascular response to this maneuver has been implicated in aircraft accidents (Lamb et al., 1958). Moreover, too vigorous a Valsalva maneuver could result in *inner ear trauma* from too sudden a pressure change, either by shearing forces or rupture of blood vessels in the inner ear when the stapes foot plate is pulled externally by sudden pressure change during inflation of the middle ear. This condition could result in vertigo and/or hearing loss. Obviously, the implications to SCUBA diving are that a prolonged and intensive Valsalva maneuver could possibly result in unconsciousness and subsequent drowning.

Hyperplastic lympoid tissue in or about the Eustachian tube may inhibit pressure equalization. Radium treatments to reduce the size of this tissue obstruction or enlarge the pharyngeal orifice of the Eustachian tube have been proposed by some physicians (Haines and Harris, 1946; Duffner, 1958). Haines and Harris report 90 percent success with radium treatment methods. *However, radium should not be used without a full understanding of its potential dangers* (Taylor, 1959).

When a diver surfaces after experiencing ear squeeze, he may spit blood which drains to the throat through the Eustachian tube. If drainage and/or discomfort persist, a physician should examine the injury and prescribe treatment. Local treatment of ear squeeze is ordinarily contraindicated. The diver should not reenter the water until healing is complete. Antibiotics may be indicated to combat infection. For a complete discussion of ear squeeze, consult Strauss (1971).

Schilling and Everley (1942) and Haines and Harris (1946) indicate that, based on the evaluation of thousands of submarine personnel subjected to pressure tests, the most frequent and most serious complication of aerotitis media is temporary or permanent impairment of auditory acuity. These findings are summarized by Taylor (1959). Haines and Harris contend that although capable of equalizing pressure in the middle ear, many subjects develop complications by letting the increasing pressure "get ahead" of them one or more times and then would equalize only after some damage had been done. *A diver should not wait for pain as a signal to equalize pressure in his ears.* The equalization maneuvers should start immediately when the diver begins his descent or at least at the first "sensation of pressure change" on the ear. Pain is an indication that barotrauma already is present.

When the eardrum ruptures, a sudden relief in pain may be experienced. If the diver's ears are exposed directy to the water, the entry of cold water into the middle ear may cause a violent upset of the sense of balance. The diver may experience extreme vertigo (dizziness) because of thermal effect on the inner ear and semicircular canal and may also become nauseated and vomit. This reaction usually subsides in a minute or so as soon as the water in the ear warms to the body temperature. Blood is generally present in the external auditory canal. Except in the presence of infection, healing takes place in a few days to a few weeks, depending on the severity of the injury. During this time, diving is prohibited and water should not be allowed to enter the external auditory canal. Antibiotics may be necessary, especially if the diver has been in polluted water.

3.2.2 Sinus Squeeze

Blockage of the sinus ostia results in *aerosinusitis*, or sinus squeeze, with painful edema and hemorrhage in the sinus cavities. These cavities are located within the skull bones and are lined with mucus membrane continuous with that of the nasal cavity (Figure 3-2). The mechanism is much the same as that described for aerotitis media. With normal gas pressure within the sinus cavity and an excess pressure applied to the membrane lining via the blood, a vacuum effect is created within the cavity. Unless the pressure is equalized, severe pain and damage to the membrane will occur. A diver who has experienced sinus squeeze will often surface with blood in his mask or will notice a small amount of blood and mucus discharge from his nose following the dive. Sinus squeeze can be avoided by refraining from diving when there is nasal congestion as a result of an allergy, cold, or infection. If discomfort develops in the sinus areas during descent, it may be relieved by the Valsalva maneuver; if not relieved, terminate the dive. Following aerosinusitis, infection may develop, as indicated by persistent pain and discharge; medical attention and systemic antibiotics are generally necessary.

In some instances the use of a long-acting nasal vasoconstrictor (decongestant) prior to diving may be beneficial (US Navy, 1963). Hubner and Sehnert (1963) surveyed a large group of divers, instructors, and physicians and found that, as the occasion demanded, 56 percent of the divers had used an oral-nasal decongestant, 75.1 percent had used nasal drops or a spray, and 19.5 percent had used an inhaler. An oral decongestant containing phenylpropanolamine

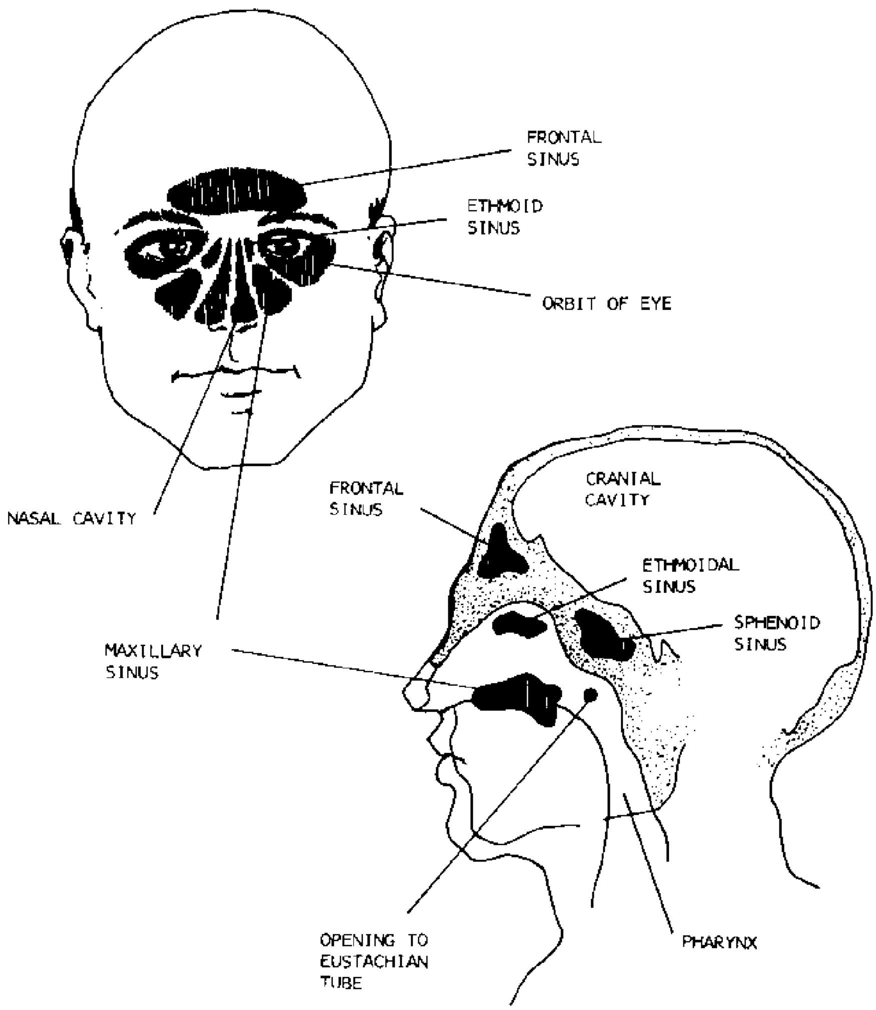

Figure 3-2. Nasal Accessory Sinuses

HCl, phenaramine maleate, and pyrilamine maleate was most frequently prescribed, and phenylephrine hydrochloride (neosynephrine) was the most commonly mentioned local decongestant. The vasoconstrictive action of this oral decongestant used as a predive prophylactic agent tends to keep the nasal passages, sinuses, and Eustachian tubes clear by shrinkage of the nasopharyngeal mucus membrane. Some discretion must be exercised in the use of decongestants due to possible individual associative reactions. It is important that the nasal spray or systemic decongestant be used on a *trial basis* at least 24 hours prior to the dive to rule out idiosyncratic reaction. Although rare, drowsiness resulting from the antihistamine or the development of marked nasal mucosal edema precludes safe diving.*

It is important to use nasal sprays properly. Dr. S. Harold Reuter (personal communication) recommends the following procedure:

1. *With the head erect,* insert nozzle in nostril, point the spray bottle in the direction of the eye, and squeeze briskly so the spray will come out in a fine mist.

2. *Then, with the head facing the floor*, insert nozzle in nostril, point the spray bottle toward the top of the ear, and squeeze briskly.

3. *Wait 5 min*--this will allow time for the *front* nasal passages to open. Then repeat 1 and 2 to open the *back* nasal passages.

4. When blowing the nose, always do so *gently,* and with the *mouth open.*

On ascent, the ears and sinuses generally vent the expanding gas without much difficulty. However, occasionally blockage may result from mucus or swelling of tissue injured during descent and result in a *reverse ear or sinus squeeze*. In the event of symptomatic developments during ascent, descend slowly to facilitate pressure equalization. The after effects of vasoconstrictors used prior to descent may produce tissue swelling in individual cases, and consequent Eustuchian tube or sinus ostia restriction.

3.2.3 Thoracic Squeeze

As a diver descends while holding his breath, the flexible portion of the thorax is compressed and the diaphragm elevated. Consequently, the air within the lungs and airways is compressed and the system assumes a more "expiratory" position. Until recently it was indicated in the literature that no difficulty is

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*For recommended oral-nasal decongestants, see last paragraph on page 3-2.

experienced until the position of maximal expiration is reached; then the volume of air equals the residual volume of the lungs plus the volume of the airways. Beyond this point, further descent while breathholding may result in pulmonary congestion, edema, and hemorrhage in the lungs. The diver may experience a sensation of chest compression, breathing difficulties, and possible chest pain. This condition is generally called *thoracic squeeze*.

Rahn (1965), however, suggested that during breathhold dives to greater depths, blood is forced into the thorax, replacing air and resulting in a significant decrease in residual volume. Using the impedance plethysmograph, Schaefer et al. (1968) made measurements of thoracic blood volume displacements during breathhold dives to depths of 130 ft. These measurements confirmed that a significant shift in blood volume into the thorax does take place. Furthermore, Robert Croft, a US Navy diver, and Jacques Mayol successfully dived to depths of 240 ft and 231 ft, respectively. These are considerably greater depths than could be predicted on the basis of total lung volume/residual volume ratios. Based on total lung volume/residual volume ratios, Mayol's depth threshhold would have been 90 ft. Theoretically, a blood shift of 980 ml into the thorax was necessary, with a corresponding replacement of air and reduction of his residual volume to approximately one-half that measured. Underwater photographs taken during the 240-ft dive show pronounced caving in of the thorax, compression of the abdomen, and skinfolds flapping around the chest. The details of these experiments are summarized by Schaefer et al. (1968).

3.2.4 Equipment-Induced Squeezes

Gas-containing structures attached to the surface of the body are potential sources of local "squeeze." Failure to equalize pressure during descent under the diver's face mask can result in damage to the skin and particularly to the eyes. The mechanism of damage is similar to that of middle ear or sinus squeeze. The most easily damaged tissues are those covering the eyeball and lining of the eyelids and the spaces around the eyeball. Excessive pressure differential may cause conjunctival and even retrobulbar hemorrhage with tension on the optic nerve and possible loss of vision. Subcutaneous hemorrhage and swelling of the facial tissue under the mask may be evident. The condition is avoided by the diver simply admitting air into his mask through his nose.

The classical form of "divers squeeze" may be encountered in helmet-closed suit (i.e., conventional deep-sea rig) diving when the pressure within the helmet suddenly drops below that of ambient. The condition results either from the loss of pressure within the supply line, with subsequent venting to a lower pressure or by sudden increase in the depth of the diver, as in a fall, without compensation by increasing gas supply pressure. The helmet itself constitutes the nonequalized rigid space, and the external pressure of the water acts to force the diver's body into it. For the same reasons, a similar condition can occur when the diver is using a surface-supplied, full face mask. The resulting injury has already been discussed in a previous section. Because of these possibilities, a nonreturn valve in the supply line at the helmet or mask is essential in all surface-supplied diving equipment. Proper diving procedures and tending are necessary to prevent falls.

A closed, watertight diving dress (suit) can also produce squeeze unless during descent, gas is admitted into the dress by some means. The squeeze is usually noted as a pinching sensation in the area of suit folds and ridges, causing welts and ecchymoses in the skin. Additionally, external ear squeeze can result, wherein the mechanism and consequences are essentially like those of middle ear squeeze. Damage to the tympanic membrane may be equally severe, though the force is applied in the opposite direction. Hemorrhagic blebs may form close to the eardrum and blood drains from the external auditory canal. The common foamed-neophrene wet-type suit generally eliminates these hazards; however, there is potential hazard with thin, tight-fitting hoods. Ear plugs are contraindicated in diving not only because of the potentiality of external ear squeeze but also because the unequalized pressure may force the ear plugs deep into the external auditory canal.

3.2.5 Gastrointestinal Squeeze

Gas pockets in the gastrointestinal tract do not produce difficulty during descent since the walls are nonrigid and equalization is accomplished by compression of the gas. However, expanding gas in the gastrointestinal tract during ascent may produce difficulties. Expansion of gas swallowed during the dive or formed as a result of eating gas-producing foods just prior to the dive can cause severe pain and is capable of producing manifestations including fainting, respiratory embarrassment, and reflex circulatory collapse.

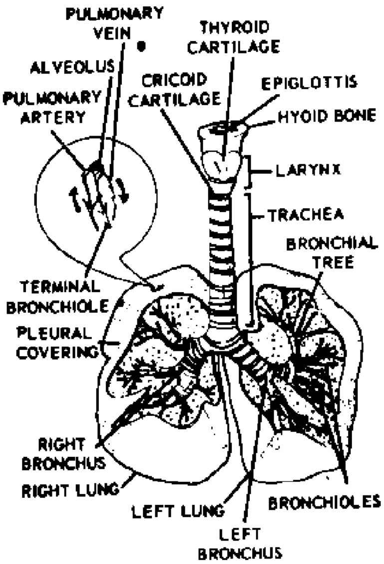
3.2.6 Dysbaric Cerebral Air Embolism and Associated Complications

Dysbaric cerebral air embolism is a severe occupational hazard associated with diving, submarine escape training, and explosive decompression in aerospace work. The condition is not to be confused with decompression sickness, which in the average case tends to be less acute. The connotation "dysbaric" is proposed by Waite et al. (1967) to differentiate this form of air embolism incurred in a diminishing ambient pressure from the accidental variety occurring at 1 atm in a hospital setting. Since air is probably the most common breathing medium for divers, the term "air" embolism is most frequently used; however, with the advent of extensive mixed-gas diving, "gas" embolism is also correct terminology.

According to the US Navy (1970 a), air embolism is probably second only to drowning as a cause of SCUBA diving fatalities. Waite et al. (1967) suggest that a "fair" number of the estimated 60 SCUBA diving deaths reported by the National Research Council for 1965 were due to air embolism. Smith (1967) suspects air embolism as a prime cause of SCUBA fatalities. The incidence of air embolism in relation to submarine escape training is summarized by Waite et al. (1967) and Miles (1962).

In a diminishing pressure situation, e.g., a diver ascending from depth, the air in the lungs is expanded because of the decreasing external pressures. If the normal exhalation route of the expanding gas is interrupted either voluntarily, as in breathholding, or involuntarily, from local respiratory tract obstruction, the intrapulmonary pressure progressively distends alveoli and ruptures of alveoli ensue. Localized partial or complete bronchial obstructions include "ball-valving" bronchial lesions, mucus, bronchospasms, etc. (Linaweaver, 1963). Walter (Smith, 1967) suggests that bronchial mucus and irritants, particularly tobacco, are prime offenders. From the point of rupture (Figure 3-3), the gas may dissect along bronchi and enter the mediastinum to create *mediastinal emphysema*. A diver with mediastinal emphysema may experience such manifestations as substernal pain, breathing difficulties, and even collapse due to direct pressure on the heart and great vessels. Cyanosis may be evident.

From the mediastinum, the gas frequently migrates into the subcutaneous tissues (*subcutaneous emphysema*), most often in the neck and supraclavicular region. This will add manifestations evident by enlargement of the neck, voice changes, breathing difficulties, and crepitation (cracking sensation) upon palpation of the neck and supraclavicular region. If there is a weakened area on the surface of the lung, such as alveolar emphysematous blebs, rupture may take place into the pleural space with the development of a *pneumothorax*. Pneumothorax is an infrequent but serious complication of diving. This may result in partial or total collapse



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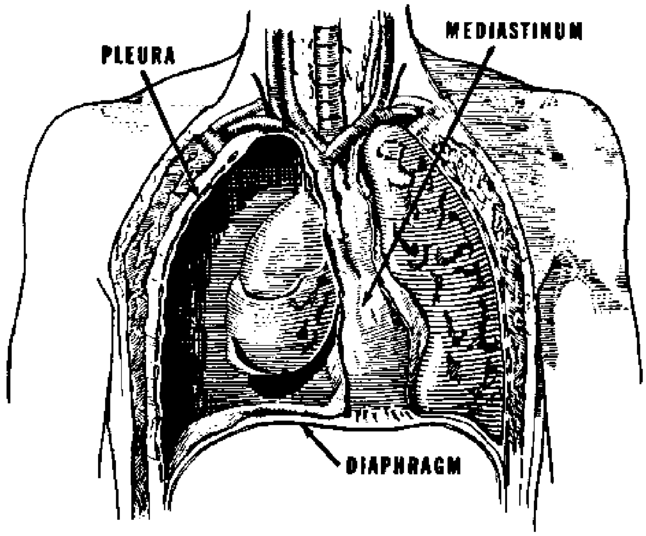

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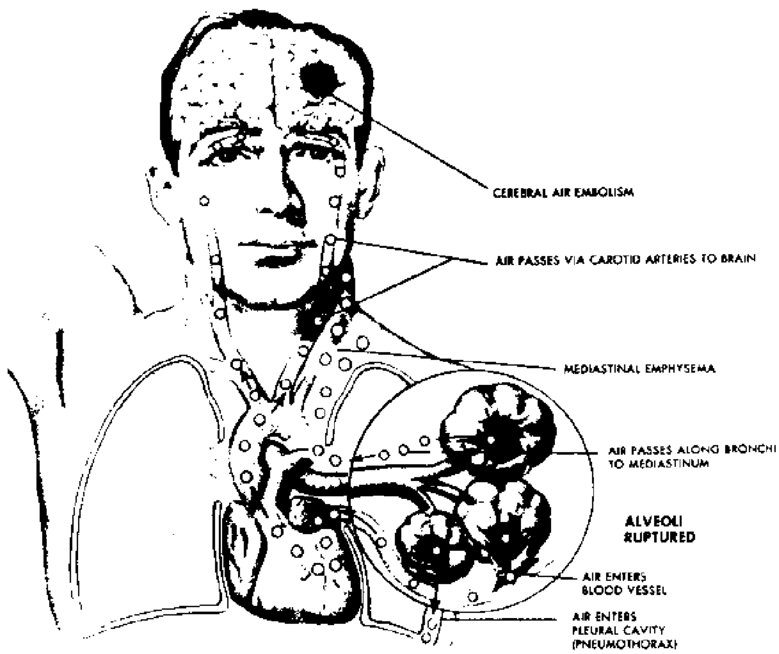

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Figure 3-3. (a) Lungs and Air Passages; (b) Collapse of Lung in a Pneumothorax; (c) Rupture of Lung Tissue and Possible Avenues of Gas Dissemination (Photo Courtesy of US Divers Co.)

of the lung on the side involved. As the diver continues ascent, the air entrapped in the pleural space expands at the expense of the collapsing lung and may eventually cause displacement of the heart. This is an extremely serious complication because both breathing and circulation are impaired. Manifestations include chest pressure and pain, breathing difficulties, and cyanosis.

The most serious consequence of alveolar rupture is the release of gas bubbles into the pulmonary circulation, and via the pulmonary vein, left heart, aorta and carotids, into the cerebral circulation. The cerebral area is most frequently affected since the diver is usually in an erect or head up position, and the bubbles tend to rise. Any bubble too large to pass through an artery will lodge and obstruct circulation to adjacent areas or organs. This obstruction is the embolus.

The wide clinical spectrum of symptoms and signs associated with cerebral air embolism include headache, vertigo, cranial nerve involvement, visual, auditory, and speech disturbances, loss of consciousness, coma, paralysis, convulsions, loss of vital signs, and death (Waite et al., 1967). Death results from coronary and/or cerebral occlusions with cardiac arrhythmias, respiratory failure, circulatory collapse, and irreversible shock (Linaweaver, 1963). The onset of symptoms is dramatic and sudden, usually occurring within seconds of surfacing, or even prior to surfacing. Many cases occur without development of any symptoms prior to unconsciousness; the diver may or may not experience discomfort or pain in the chest prior to or during alveoli rupture. The tearing of lung tissue often results in bloody froth at the mouth; however, the absence of bloody froth does not preclude the possibility of air embolism (US Navy, 1970 a).

Dysbaric cerebral air embolism and its related conditions are best prevented by observing the following procedures or rules established by the US Navy (1963) and supplemented by me:

- *Careful selection of personnel:* Each candidate for diving duty or training must undergo a complete medical examination, including an evaluation of his medical history. History of tuberculosis, asthma, or chronic pulmonary disease may be disqualifying; the lungs shall be normal as determined by physical and X-ray examination (chest roentgenograms taken at full inspiration and full expiration). The daily condition of the diver must also be considered; a severe cold (especially with respiratory complications) is temporarily disqualifying.

- *Proper, intensive training of every diver in the physics and physiology involved in diving:* Many cases of air embolism have occurred simply because the diver did not understand Boyle's law and its application to diving. A thorough understanding of diving physiology and an awareness of the consequences of air embolism promotes a positive attitude toward the observance of basic diving procedures and safety standards.

- *Proper, intensive training of every diver in the use of diving equipment and diving and safety procedures:* This is especially important in the use of SCUBA. When an improperly trained diver loses his gas supply underwater, his first overwhelming instinct is to hold his breath and surface immediately. Training and proper indoctrination give the individual confidence which is so important during times of danger so that intelligent and proper action will be taken, thus avoiding panic.

- *Never hold your breath during ascent from a dive in which a breathing apparatus was used:* Breathe regularly during ascent. When the apparatus fails or gas supply is exhausted and a free ascent is unavoidable, exhale continuously during ascent to prevent overexpansion of the lungs.

- *Divers should avoid smoking:* There is sufficient evidence to indicate that smoking causes serious irregularities in the lung tissue and excessive bronchial mucus. Subsequent blockage of airways and weakened tissue can result in rupture of lung tissue.

The only recognized standard and effective treatment of cerebral air embolism is the recompression method. Complete and authoritative discussions of this topic are available from the US Navy (1970 a), and Dueker (1971). Recompression procedures and principles are given in the section of recompression in this text.

3.3 Impaired Consciousness During Breathhold Diving

Prolonged voluntary breathholding while swimming underwater can result in loss of consciousness and subsequent drowning. Craig (1961 a, 1961 b) studied cases of near drownings and deaths resulting from loss of consciousness while swimming underwater and found that during such circumstances diving accidents were explainable by loss of consciousness due to *hypoxia*. Hyperventilation is a common practice among underwater swimmers, i.e., skin divers, sponge and pearl divers, etc. By hyperventilation the swimmer can significantly deplete the carbon dioxide (CO_2) stores of the body. The partial pressure of CO_2 (pCO_2) in the nerve tissue regulating respiration appears to be the primary stimulus to respiration, with comparatively little stimulus derived from low oxygen partial pressures (pO_2). While swimming underwater the diver uses O_2 and produces CO_2; however, since the CO_2 is used for replacement of the subnormal body CO_2 stores, there is insufficient CO_2 stimulus for respiration. When the oxygen consumption is increased, as in the first few seconds of exercise, the pO_2 may decrease to a degree incompatible with cerebral function before the rise in pCO_2 commands the diver to surface for air. Loss of consciousness can result from hypoxia (or anoxia, which has about the same meaning) with little specific warning. The victim may actually continue his activity between the time of loss of consciousness and final collapse.

This condition is further complicated by increased ambient pressure and ascent from depth. Paulev (1968) and Paulev and Naeraa (1967) conducted controlled experiments to study the mechanism of hypoxia and carbon dioxide retention during the following breathholding dives. During these dives the alveolar oxygen tension (pAO_2) decreases linearly, but remains high enough to reoxygenate the blood quite completely during most of the dive. However, staying on the bottom longer than 90 sec yielded significantly low pAO_2 and arterial O_2 tension (paO_2). The low pAO_2 and the Bohr effect (the greater the $paCO_2$, the lower the hemoglobin O_2 saturation is) has resulted in a significant fall in O_2 saturation; thus, the blood cannot carry as much O_2 from the lungs to the tissue as before. Some divers have been reported to have lost consciousness at the bottom, and they possibly have contracted the dangerous combination of a low pAO_2 and a very high $pACO_2$.

Shortly after reaching the bottom a diver may experience a subjective "breaking point" approach sensation due to increased $paCO_2$ stimulus plus stimuli elicited from smaller lung volume. This sensation is easily overcome by the willpower of trained breathhold divers. The expert skin diver can actually "condition" himself to voluntarily or involuntarily ignore the breaking-point sensation (or urge to breathe) and over a period of time becomes inured to the subsequent pCO_2 buildup that would drive the average person to the surface for air. During ascent, a relief of the breaking-point sensation is experienced because the lung volume increases and the $pACO_2$ falls, even though oxygen may actually diffuse from the alveoli to the blood at a slower rate due to $pACO_2$ decrease. Since the pAO_2 may fall below the venous pO_2, the possibility for O_2 transfer from the blood to the lungs is present. Blood oxygen stores may be depleted rapidly. If during ascent, blood deprived of oxygen arrives at the cerebral cortex, the diver may lose consciousness with little or no warning before or just as he reaches the surface. Unconsciousness during ascent when the diver is below the "buoyance point" is a potentially fatal condition. Ironically, many competitive skin divers wear lead weight belts, making them negatively buoyant for effortless diving.

Bond (1965) condemns competitive breathholding exercises and contests, even under the auspices of a good organization, and anyone who wears excessive weights. Unfortunately, competitive breathholding contests are a common occurrence in nearly every American swimming pool. Bond cites one such experience involving a 16-year-old male in excellent physical condition participating in a contest conducted in a swimming pool. Wearing a face mask and weight belt the young man settled to the bottom of the pool and remained there for 9 min in full view of almost 200 spectators. Finally, he was hauled to the surface in a state of unconsciousness and not breathing. His breathing was successfully revived; however, subsequent examination and electro-encephalograms revealed no cortical activity. In other words, this young man was now doomed to lead the life of a vegetable for the rest of his days.

Neurological phenomena, including unconsciousness as a result of decompression sickness, may occur from repeated breathhold dives to great depths (Paulev, 1965; 1968). The increase in the paN_2 is high at about 20 m depth. Although the volume of N_2 absorbed during each dive may be small, the increase in tissue $\bar{p}N_2$ (ptN_2) could account for the occurrence of N_2 containing bubbles in the tissue following many repetitive and rapid alterations in ambient pressure. Bond (1965) relates a personal experience in which he was a victim of decompression sickness as a result of 7 hr and 20 min of continuous breathhold skin diving to depths of 80-100 ft. Fortunately, such cases are rare, probably because most human divers cannot breathhold dive deep enough nor often enough to contract decompression sickness.

Cross (1962, 1965) discussed the dreaded disease of Tuamotus pearl divers, "taravana." These pearl divers are true skin divers; they use no breathing apparatus or air supply for their underwater work. Yet, many of those stricken with "taravana" exhibit symptoms like those of classic decompression sickness--vertigo, paralysis, unconsciousness, and insanity. These divers may make as many as 6-14 dives/hr to depths up to 150 ft and stay submerged an average of 1 min and 35 sec. This schedule is continued daily throughout the pearl diving season. On one exceptionally good diving day (good weather and seas), Cross observed that 47 divers were stricken with "taravana." Thirty-four of the 37 suffered vertigo, nausea, and dizziness, and 11 surfaced paralyzed or unconscious and were rescued. Of the 11, six were partially or completely paralyzed, two were "mentally affected," and two young men died.

Cross suggests that anoxia is the principal cause of "taravana," with its effects on the central nervous system and the brain accounting for the many and varied symptoms. He points out that Mangareva divers space their dives 15 min apart, instead of the 4-8 min used by the Tuamotus divers, and do not suffer from "taravana."

Certainly anoxia or hypoxia explains many of the symptoms, and it should also be stated that continuous daily and seasonal exposure of brain tissue cells to hypoxia conditions could possibly result in cumulative and irreversible brain damage. However, decompression sickness, as discussed by Paulev (1965, 1968), is also an equally significant explanation, especially when considering the cumulative underwater time and depth.

Frequently, loss of consciousness while underwater is referred to as shallow-water or underwater blackout. The US Navy (1963) defines shallow-water blackout as an "accident in which a diver loses consciousness, presumably from carbon dioxide excess without an adequate respiratory warning." Bond (1965) considers lowering of oxygen levels of vital organs as a primary cause.*

3.4 Breathing Media Contamination

3.4.1 Carbon Monoxide Poisoning

Carbon monoxide (CO) is probably the most serious breathing media contaminant. Carbon monoxide readily combines with the blood hemoglobin, forming COHb, and renders the hemoglobin incapable of transporting sufficient oxygen. Hemoglobin, in fact, combines with CO about 200 times as readily as with oxygen. Shepard et al.

*For a more comprehensive review of breathholding, consult DuBois (1955) and Rahn (1965).

(1958) have shown that the diffusion capacity for CO increases progressively with increasing exercise. When this occurs, tissue anoxia develops even though the supply of oxygen to the lungs is ample. At sea level the toxic effect of CO is proportional to the amount of COHb formed; however, at depth, a diver may tolerate a considerably higher ratio of COHb because some of the oxygen transport requirements are met by the oxygen in solution (due to increased pO_2 at depth). However, since the reconversion of COHb to oxyhemoglobin is relatively slow compared to the time required for COHb to form, the diver may develop symptoms of CO poisoning immediately on ascent (US National Research Council, 1956).

Consequently, contamination of SCUBA air with even small amounts of carbon monoxide can be very dangerous. At present, specifications and purity standards for high-pressure, compressed, diver's breathing air allow for a maximum of 10 (0.001 percent) ppm carbon monoxide (Anonymous, 1964; US Navy, 1970 a). On several occasions I have analyzed air obtained from "dive shops" and found concentrations of CO beyond the recommended limits. *Occupational Health* (1963) reports that upon examination of 25 SCUBA tanks for presence of CO, only two tanks showed no CO present, 18 tanks had CO concentrations between 10 and 25 ppm, and five of the samples had concentrations greater than 25 ppm, with one sample of 75 ppm. The diver must be certain that the air supply meets recommended purity standards. SCUBA air supply must be obtained from *reliable* sources. Periodic air analyses are recommended; organizations conducting diving operations should include CO gas analysis equipment in their diving lockers. Methods of analysis, safe limits, and methods of removal are discussed in US Navy (1970 a).

The wide spectrum of symptoms associated with carbon monoxide poisoning include headache, dizziness, nausea, weakness, confusion, and other mental changes. The tender or diving partner may note failure to respond, clumsiness, and bad judgment. Frequently no symptoms are evident; the diver may lose consciousness without warning and breathing may cease. In general, the symptoms parallel those of other forms of anoxia, with one exception--the victim's coloration is red instead of blue. In spite of the displacement of oxygen, hemoglobin combined with CO has a bright red color. Consequently, a victim who becomes anoxic because of carbon monoxide poisoning often exhibits an unnatural redness of lips, nail beds, and sometimes the skin.

When carbon monoxide poisoning is indicated, get the victim into fresh air (or noncontaminated area) as soon as possible. If breathing has stopped, start artificial respiration at once.

The victim should be given oxygen as soon as possible; administration of oxygen increases the amount of oxygen reaching the tissue in spite of the inactivity of the hemoglobin and it also accelerates the elimination of CO from the blood. A carbon monoxide victim should be treated under medical supervision. The treatment of carbon monoxide victims with oxygen at 2 atm pressure has been described by many investigators, including Smith et al. (1962). Records of rapid and complete recovery are establishing hyperbaric oxygen as a standard method of treatment.

Contamination with carbon monoxide can arise from two primary sources:

1. The gas may be present in the intake air from having the compressor intake located too close to or downwind from the exhaust of a gasoline-driven engine or other source of exhaust gas. In large cities and industrial areas, CO is a common atmospheric pollutant and may rise, at times, beyond the safe concentration level for diver's air. Consequently, the air supplier must be constantly aware of atmospheric pollution levels and/or take measures to remove excessive CO during the air compression process.

2. Oil-lubricated compressors, particularly when not operated or maintained properly, can develop high cylinder temperatures that cause partial combustion (oil "flashing" or "dieseling") of the lubrication oil. All breathing air compressors must be maintained in accordance with manufacturer's specifications.

3.4.2 Oil-Vapor Contamination of Air Supply

Oil vapor, from oil-lubricated compressors, is probably the most common contaminator of SCUBA air supply. Oil fumes give an unpleasant taste and odor to the breathing mixture, and under pressure the concentration may be sufficient to cause pulmonary irritation, cough, and in extreme cases, pneumonia. Do not use contaminated air; charge SCUBA cylinders at a reliable facility. Avoidance of excessive oil vapor in compressed air requires careful and regular compressor maintenance, water and oil vapor condensors, and an effective filtering system.

3.4.3 Carbon Dioxide Excess

Carbon dioxide (CO_2) is a natural by-product of oxidation and metabolism. The CO_2 tension in the human body increases with the rate of production due to physical exertion and inadequate ventilation of the lungs. Under normal conditions CO_2 is the primary respiratory stimulant to the respiratory center in the medulla. Normal concentrations of CO_2 in atmospheric air are 0.04 percent and a pCO_2 of 40 mm Hg is the normal alveolar tension. Breathing a mixture of 2 percent CO_2 slightly increases the respiratory rate. The effects of CO_2 are dependent upon the pCO_2. In accordance with Dalton's law of partial pressures, a 2 percent CO_2 mixture at the surface (1 atm) will at 132 ft (5 atm) have essentially the same effects as a 10 percent mixture would at the surface.

The effects of increased carbon dioxide content in the respired air have been investigated by many researchers. Greenbaum and Hoff (1966) list more than 300 papers on carbon dioxide's effects; special mention is made of a report by the US National Research Council (1956). The effects of increased pCO_2 on body functions are extensive and variable. Adequate respiratory ventilation is of considerable importance when considering the design of all diving apparatus, recompression chambers, underwater habitats, submersibles, etc. The following discussion will only include those aspects of carbon dioxide excess relative to operational diving. Miles (1962) indicates that there has been a wide tendency to use carbon dioxide as an underlying cause of many of the accidents and illnesses encountered in diving. It has been blamed for nitrogen narcosis, oxygen poisoning, shallow-water blackout, and as contributory to decompression sickness. Accidents with no obvious cause are frequently attributed to carbon dioxide excess. The recent death of a US Navy SEALAB III aquanaut was attributed to carbon dioxide poisoning due to failure to fill a breathing apparatus filter canister with "Baralyme" (a CO_2 absorbent) (Anonymous, 1969).

As a diver without breathing apparatus descends, the alveolar pressure of carbon dioxide does not rise appreciably because of absorption by the circulating blood to maintain a pCO_2 of about 40 mm Hg. During a breathhold dive the rise in alveolar CO_2 is due to the accumulation of gas from metabolic processes. For all intents and purposes, carbon dioxide excess can be considered secondary to anoxia in loss of consciousness while breathhold diving. Voluntary lowering of the normal pCO_2 by hyperventilation prior to the dive retards the respiratory response and enhances the development of hypoxia.

In diving with breathing apparatus, excessive accumulation may result when the carbon dioxide absorbent unit is inefficient or exhausted in closed and semiclosed circuit SCUBA and mixed-gas helmet rigs or when there is an inadequate gas supply to sufficiently ventilate the helmet or mask. The resulting accumulation and subsequent inhalation of carbon dioxide (5 percent concentration) produces respiratory stimulation (i.e., panting, breathlessness, distress, etc.), cerebral dilation, and headache. As the concentrations increase, the diver may become confused, irrational, and drowsy, and if the concentration rises above 10 percent, the diver will generally lose consciousness.

Conditions which enhance the retention of CO_2 in the body include unusual exertion, inadequate ventilation, high oxygen tensions, increased density of breathing medium, and inadequate gas supply to ventilate the breathing system and remove carbon dioxide; this is extremely important under conditions of heavy exertion. Increased alveolar oxygen pressure affects the carbon dioxide response (Lloyd et al., 1958; Lambertsen et al., 1963). Increased breathing resistance, whether due to apparatus design or gas density, favors CO_2 retention and therefore decreases sensitivity to CO_2 (Lanphier, 1958). Lanphier favors abandoning nitrogen-oxygen mixtures in favor of less dense helium-oxygen mixtures for mixed-gas SCUBA diving. Eldridge and Davis (1959) concur with Lanphier in that increased breathing resistance causes pCO_2 and exertion levels to rise in parallel, whereas ventilation response remains constant, or even decreases.

If a diver does not ventilate his lungs sufficiently to eliminate as much CO_2 as he is producing, he can poison himself (US Navy, 1963). A number of accidents in which the diver has lost consciousness for no apparent reason have been explained on this basis. Deliberate reduction in breathing rate to conserve air in the use of open-circuit SCUBA is an extremely dangerous practice. Most authorities consider it better to breathe normally and consume more air than to practice periods of breathholding between inspirations and risk the lethal consequences of CO_2 build-up.

3.5 Gas Narcosis and Toxicity

3.5.1. Inert-Gas Narcosis

Among the major factors likely to cause performance impairment in divers at increased ambient pressures is inert-gas narcosis. Although the common inert gases (nitrogen and helium) associated with diving are physiologically inert under normal conditions, they have distinct anesthetic properties when the partial pressure is sufficiently high. The problem of compressed air "intoxication" has long been recognized by divers and researchers. Behnke et al. (1935) were among the first to attribute these effects to high partial pressure of nitrogen. Many theories of compressed air intoxication were advanced by various investigators. Damant (1930) attributed part of the intoxicating effects to the increased oxygen pressure. Bean (1950) expressed doubt that nitrogen was the responsible agent, and contended that the sole causative factor is a rise in body CO_2 tension brought about by raised gas density. Manifestations of anxiety (Hill and Greenwood, 1906) and claustrophobia, a combination of all of the aforementioned factors, or the pressure itself (Shilling and Willgrube, 1937) have also been suggested as causes. However, encephalographic studies by Bennett and Glass (1961) leave little doubt that high nitrogen pressure constitutes an important causative factor of compressed air narcosis. Associated causes may include the density and oxygen partial pressure of the respired mixture, which, in turn, may cause an increased carbon dioxide tension that synergistically potentiates the narcosis (Bennett, 1963). Taylor (1962), however, finds that CO_2 does not contribute to the causation of the narcosis. Bennett (1966) considers the problem of compressed air intoxication in detail and Miller (1963) discusses the theories of inert-gas narcosis.

Nitrogen narcosis, or compressed air intoxication (US Navy, 1963; Lanphier, 1957), characterized by symptoms similar to alcohol intoxication, first becomes evident at a depth of about 100 ft. Beyond this depth, most compressed air divers show some impairment of thought, judgment, and the ability to perform tasks that require mental or motor skill. Such impairment, even if mild, obviously constitutes a potential hazard to the diver's safety. Most divers lose their effectiveness at about 200 ft, and at about 250 ft, the average diver is, for all practical purposes, useless and a menace to himself.

Like alcohol, the effects of nitrogen vary with the individual person, and, by conscious effort, the hazards can be minimized within certain limits. Miles (1962) tabulates the sequence of events for the average man under the influence of high-pressure nitrogen in a breathing medium of air as follows:

- *100-150 ft:* Light head, increasing self-confidence, loss of fine discrimination, and some euphoria.

- *150-200 ft:* Joviality and garrulousness, perhaps some dizziness.

- *200-250 ft:* Laughter may be uncontrolled and approach hysteria. Power of communication lessened, and mistakes made in simple motor and mental tasks. May be peripheral numbness and tingling. Less attention paid to personal safety. Delayed response to signals and stimuli.

- *300 ft:* Depression, and loss of clear thinking. Impaired neuromuscular coordination.

- *350 ft:* May approach unconsciousness, with the additional danger of oxygen poisoning.

Several predisposing factors may advance the onset of symptoms and ameliorating factors may help to increase the tolerance to nitrogen narcosis (Miles, 1962). Alcohol taken prior to pressurization greatly enhances the nitrogen effect, the two being almost additive. Fatigue will increase susceptability, as will any circumstance causing retention of carbon dioxide. In the inexperienced diver, anxiety is likely to advance the onset of symptoms. However, experience, strong will, and frequent deep diving all help to increase the tolerance to high-nitrogen tensions. Bennett (1963) suggests that certain drugs might lessen the narcotic effects of nitrogen.

The principles of prevention lie in common sense and proper diving procedures. Compressed air divers must observe definite depth limitations. The US Navy (1970 a) considers 300 ft as an absolute limit for surface-supplied air diving and 130 ft as the maximum air working limit for SCUBA divers, except specially trained personnel. For dives to depths greater than can be reached safely by air divers, helium-oxygen mixtures are employed. Published accounts of "sport" dives, using compressed-air SCUBA, to depths of 200-300 ft are not uncommon, and one account mentions a "record" dive to 390 ft. Recently another "record" SCUBA dive (air) of 437 ft was reported in a local newspaper (*The Grand Rapids Press*, 29 January 1969). The trained diver need not be reminded that even 200 ft is well beyond the depth limit deemed reasonable and proper by the Navy for compressed-air SCUBA. Not only is the diver subjected to extremely high pN_2 and subsequently nitrogen narcosis but also oxygen poisoning and decompression sickness. US Navy (1970 a) standard air decompression tables are calculated to only 300 ft. The publication of such "stunts" tends to lure the unsuspecting novice to depths beyond the capacity of his equipment, knowledge, skill, and physiology.

The treatment of gas narcosis is no problem. Simply reduce pressure (ascend), and recovery is complete, except in severe cases, where, in some cases, temporary amnesia and, in all cases, tiredness due to pressure exist (Miles, 1962).

3.5.2 Oxygen Toxicity

The toxic effects of excess oxygen are of considerable importance in diving and hyperbaric research, and the mechanism of these effects is not yet thoroughly understood. The administration of 100 percent oxygen to humans continuously for 24 hr at normal atmospheric pressures causes substernal distress in 86 percent of subjects, and under pressures above 1.0 atm for a sufficiently long time or at sufficiently high pressure eventually leads to the development of oxygen toxicity characterized by general convulsions (Greenbaum and Hoff, 1966). The cause of these convulsions is not yet completely understood in spite of considerable research in this field.

Oxygen toxicity is a function of pressure and duration. The safe period of oxygen inhalation is further reduced by immersion, exercise, and carbon dioxide inhalation. High-pressure, oxygen poisoning affecting the brain and causing convulsions can definitely occur at pO_2 of 2.0 atm and sometimes even lower (US Navy, 1970 a). Oxygen tolerance varies with individual divers and may also vary from day to day. The US Navy has established an "oxygen tolerance test" for divers to detect those with unusual susceptability which requires breathing pure oxygen for 30 min at 60 ft in a dry chamber. The US Navy recommends a normal 25-ft depth limit and for exceptional operations a 40-ft limit for pure oxygen breathing during working dives; dive duration is limited in accordance with depth. Emerson (1966) recommends an allowed pO_2 range of 0.2-0.4 atm for prolonged mixed-gas diving exposures and suggests that 0.2-1.5 atm might be acceptable for short durations.

Warning symptoms of oxygen toxicity, in order, are: muscular twitching, nausea, abnormalities of vision and hearing, difficulty in breathing, anxiety and confusion, unusual fatigue, incoordination, and convulsions. Oxygen poisoning is reversible and the convulsions are not dangerous in themselves but may result in physical injury, air embolism (uncontrolled ascent), and drowning (particularly with SCUBA). The convulsions are usually self-terminating with no apparent lasting effects. The mechanism of oxygen poisoning, although presently obscure, may be considered to be a direct effect through interference with enzyme systems. For an authoritative discussion of oxygen toxicity, the reader is referred to the US National Research Council (1966).

3.6 Decompression Sickness: Air Diving

The term "decompression sickness" refers to the "signs, symptoms and basic underlying pathological processes caused by rapid reduction in barometric pressure from high pressure to one atmosphere, or from any higher to any lower level of pressure" (Greenbaum and Hoff, 1966). The basic underlying pathologic process in decompression sickness is the local formation of bubbles in body tissue, both intravascular and extravascular. The resulting symptoms vary widely in nature and intensity depending on the location and magnitude of bubble formation. When the diver is breathing air, the primary constituent of these bubbles is nitrogen with a small fraction of carbon dioxide.

To understand the basic causes of the bubble formation phenomenon, it is necessary to examine what happens to air when breathed under increased ambient pressure. In accordance with the laws of partial pressures, the amount of a given gas that will dissolve in a given liquid is determined by the percentage of that gas in the total mixture and by the ambient pressure. When the pressure of the gas mixture is increased, a pressure gradient exists between the tensions of the dissolved and undissolved phases of the gas. This gradient drives each gas into solution in proportion to its partial pressure until an equilibrium is established between the dissolved and undissolved phases of the gas. If the ambient pressure is then decreased, the tension of the gas in the dissolved phase exceeds that of the gas phase, and the pressure gradient is reversed. The factor of *time* for equilibrium to be established in either direction is a principal factor in the discussion of decompression sickness.

Nitrogen is the only principal component of air that is inert; it therefore is unaltered in the respiratory process and, for all practical purposes, quantitatively obeys purely physical laws. Consequently, at gaseous equilibrium, the partial pressure values of nitrogen in the alveolar air, venous and arterial blood, and body tissues are identical. Oxygen and carbon dioxide are actively functional in the metabolic processes and under ordinary diving circumstances, the metabolic cushion renders the tissue tensions of these two gases of little significance in the mechanism of bubble formation (Dewey, 1962).

Nitrogen will not dissolve in all body tissue at the same rate or in the same amount. This is because nitrogen is transported from the alveoli to the tissue in solution by the blood. Consequently, tissues rich in blood supply will equilibrate at a faster rate than those having more limited circulation (Jones, 1951). Nitrogen is approximately five times more soluble in fat than in water (Vernon, 1907); tissues high in lipid content (e.g., spinal cord, bone marrow, and fat deposits) must take up a proportionally greater amount of nitrogen before saturation (equilibrium) is reached (Dewey, 1962). When the pressure gradient is reversed, the slowest tissues to release all extra nitrogen will again be those with limited circulation or high lipid content. Behnke et al. (1935) determined that, after complete saturation of all tissues, elimination of all excess nitrogen requires approximately 12 hr. About 75 percent of this nitrogen is eliminated in the first 2.5 hr.

From the diver's point of view, the degree of tissue saturation and, consequently, the amount of time required for tissue desaturation (subsequent decompression time) is dependent upon the depth, or pressure, of the dive and the amount of time at depth.

The mechanism of bubble formation is summarized by Dewey (1962). Bubbles tend to form in any tissues that are saturated with nitrogen whenever the ambient pressure is reduced to a point where a "steep" pressure gradient is driving the gas out of solution. Haldane et al. (1908) first postulated that when the tissue partial pressure of nitrogen is more than twice that of the ambient partial pressure of nitrogen, symptom-producing bubble formation will occur. Once this 2:1 threshold pressure gradient is exceeded, the number and size of symptom-producing bubbles formed will be directly proportional to the magnitude of the disparity between these two partial pressures. Under these conditions, the rate of diffusion of gas from the tissues into the expired air, via the blood and alveolar membrane, is too slow to cope with the volume of nitrogen evolved. Hence, the nitrogen comes out of solution locally in the tissue in the form of bubbles. It is probable that microscopic bubble formation ("silent bubbles") occurs in parts of the body without giving rise to symptomatic manifestations and that these bubbles may cause chronic delayed damage such as aseptic bone necrosis (Greenbaum and Hoff, 1966). Bateman (1951) indicates that some degree of bubble formation probably occurs whenever the tissue partial pressure of nitrogen even moderately exceeds that of the surrounding atmosphere.

Aseptic bone necrosis refers to destructive sclerotic and cystic changes in bone which are not infectious in origin. It may occur in association with a variety of conditions such as chronic alcoholism, pancreatitis, sickle cell anemia, and ailments stemming from pressurization and depressurization. Historically, aseptic bone necrosis was known as caisson disease of the bone because it was diagnosed primarily in caisson workers. Aseptic bone necrosis is characterized by lesions in long bones such as the femur. Long-bone shaft lesions are generally asymptomatic and may be replaced to some extent by new bone growth with time. If the lesions occur in weight-bearing joints such as the head of the femur, the consequences can be serious. Eventually, collapse of the bone may result and the victim may be crippled in the area affected. Complications may also occur in the articular cartilage of the joints. The cartilage may break down and be replaced by a fibro-cartilage similar in appearance to that seen in arthritis.

The etiology of aseptic bone necrosis still has not been unequivocally demonstrated. Some investigators suggest that complications may arise from excessive compression rates rather than decompression sickness. The compression phase causes an increase in the osmotic pressure of the blood. In response to a pressure gradient between the blood and bone tissues, plasma water is shifted from the blood vessels into the tissue space of the bone, thus restricting bone blood flow. Some investigators suggest that there is a correlation between aseptic bone necrosis and the number of compression/decompression phases. Others indicate a relation to the effects of elevated oxygen pressure. A brief history and a summary of the current status of aseptic bone necrosis research is given by Karatinos (1971). Until more conclusive studies are completed, the diver must assume that there is a relationship between this condition and inadequate decompression and/or decompression sickness.

Obesity, physiologic aging, excessive physical exertion during the dive, and poor physical condition are factors predisposing a diver to decompression sickness (Dewey, 1962). As previously pointed out, fatty tissues constitute a large nitrogen reservoir due to the 5:1 oil-water solubility ratio. During a deep or lengthy dive, a considerable amount of nitrogen is dissolved in the body tissues. Obviously, if the diver is obese, during ascent the blood--essentially a watery tissue--will not be capable of transporting in solution the increased volume of gas evolved from the excess fatty tissues. Consequently, the blood will supersaturate and lead to intravascular bubble formation on the capillary level. This will result in subsequent supersaturation and extravascular bubble formation in "blocked" tissue. Aging introduces an increasing proportion of tissue with sluggish circulation and, therefore, the increased possibility of local bubble formation.

Excessive physical exertion increases the respiration rate and the rate of circulation of the total blood volume. Consequently, during excess exertion under pressure, larger amounts of nitrogen are transported to the tissue per unit of time than normally.

Consider the circumstances where a diver is working hard underwater, e.g., moving heavy objects, swimming against a strong current, etc. This diver's tissues may absorb excessive nitrogen equivalent to 10-20 min of extra diving time under normal conditions, and if he was on a dive schedule of 60 min to 60 ft (the "no-decompression" limit for that depth), he may suffer decompression sickness if he surfaces without decompression stops. Poor physical condition is a direct extension of the above situation.

Harvey et al. (1946) demonstrated that forceful movement of muscles and joints under increased ambient pressure results in an increase in bubble formation at those sites during decompression. Excessive carbon dioxide build-up in tissue has also been empirically and experimentally observed to lower the threshold for bubble formation during ascent (Blinks et al., 1951). SCUBA divers commonly use methods, e.g., skip breathing or controlled breathing, to lower air utilization and increase dive time. These practices can result in excessive carbon dioxide retention in tissue and could possibly be a factor predisposing a diver to decompression sickness.

Dr. Glen Egstrom (Tzimoulis, 1971) suggests that negative pressure breathing (as when using SCUBA) triggers diuresis. This loss of fluid from the body via diuresis, combined with fluid loss associated with breathing dry air, causes a degree of dehydration which may well reduce the efficiency of the circulatory system. Reduced circulatory efficiency may in turn modify the normal nitrogen absorption/elimination functions and contribute to the formation of extravascular bubbles, i.e., decompression sickness. Consequently, it is possible that drinking large quantities of liquid (such as fruit juice and water) prior to and between dives, could be significant in avoiding decompression sickness.

Most divers do not realize how important it is to avoid drinking alcoholic beverages before and during dives. The immediate apparent effects such as mental disorientation, impaired physical coordination, vertigo, poor judgment, and general physical weakness are serious enough in themselves to disqualify the diver. However, it is also an established medical fact that alcohol produces a diuretic effect, thereby causing a dehydration of the body. This results in blood thickening and reduced circulatory efficiency, which could contribute to the onset of decompression sickness. It is recommended that the diver refrain from alcohol for 36-48 hr before diving.

Needless to say, these "modifying factors" cannot be overlooked in operational diving. If all of these factors were accounted for in standard air decompression tables (US Navy, 1970 a), the tables would be impractical for normal diving and divers. Consequently, the discretion of the diving officer, diving supervisor, and the diver himself must be relied upon to take these factors into account when planning the dive schedule. Let's recall the 60-min dive involving heavy exertion at a depth of 60 ft. The trained and knowledgable diving officer, supervisor, or diver will use the 70-ft/70-min schedule to determine the decompression for this dive even though the actual bottom time was 60 min. Instead of surfacing directly with "no-decompression," the diver holds at 10 ft for 14 min to rid his body of possible excess nitrogen. Fourteen minutes is a small price to pay when one considers the possibility of the many hours in a recompression chamber required to treat decompression sickness.

Divers are cautioned with regard to use of the US Navy standard air decompression tables for exceptional exposures (Tables 1-14, Appendix C). Although current data is inconclusive, it is suggested by some medical personnel that these decompression schedules are not adequate. A significant number of skin "hits" have been observed by University of Michigan personnel. Until further information is available, it is suggested that dives beyond 190 ft on air be avoided whenever possible.

The simple one-compartment decompression meter (Anderson, 1967; Somers, 1970) is increasing in popularity among divers, particularly SCUBA divers. This meter is designed to simulate the physiological processes of nitrogen absorption and elimination by the human body and automatically computes the diver's decompression requirements. Although these meters appear to be very satisfactory for "normal" shallow-water diving operations, they do not take into account the diver's physical condition, excessive physical exertion, and other factors affecting individual absorption and elimination of nitrogen. I am familiar with one case of decompression sickness that is probably a result of these "modifying" factors not being taken into account when using a decompression meter. Following the meter "read-out," the diver suffered a severe case of decompression sickness following his third or fourth repetitive working dive in cold water to depths exceeding 80 ft. Also it should be pointed out that these meters are designed to function relative to the mid-level tissue nitrogen absorption and elimination times and are not recommended for extremely deep and/or long-duration dives on which the higher tissues absorb more nitrogen.

The symptoms of decompression sickness are variable in their nature and intensity, depending on the location and size of the bubbles. Localized pain is the most predominant symptom, occurring in about 89 percent of all cases, and is the only symptom in roughly 68 percent of cases. The onset of pain, sometimes likened to that of a severe toothache, is often gradual with fairly rapid increase in severity; untreated, it almost invaribly progresses to an "unbearable" stage. The location of the pain is usually rather localized at first and extends centrifugally to involve a progressively larger area. Generally, the pain is neither aggravated nor alleviated by motion or local palpation.

Joints and tendinous structures are the most common location of pain symptoms. Various theories regarding the mechanism of pain production have been postulated, and Dewey finds Nims' (1951) theory most acceptable. Nims reasons that a gaseous bubble developing in the tissue must displace and deform adjacent structures, which possess varing degrees of elasticity and deformation resistance. Furthermore, given the same amount of gas, the deformation pressure in a "tight" tissue, such as a tendon, ligament, and joint capsule, must be greater than that in "loose" tissue, such as fat. When this deformation pressure exceeds a certain threshold value, nerve fibers are stimulated by the mechanical deformation. On this basis, "tight" tissues are the most probable sites for symptom occurrence. This has been verified by experience and experimentation (Inman and Saunders, 1944).

Localized skin rash and itching is experienced fairly often by divers during or immediately following decompression. A peculiarly irregular, modified "rash" is the most common type of skin lesion related to decompression sickness. The distribution tends to be related to subcutaneous fat deposits and is characteristically found, in order of frequency, in the pectoral region, back of shoulders, upper abdomen, forearms, and thighs. Recompression causes complete disappearance of the visible lesion; however, tenderness may persist for several days. The underlying pathologic changes and mechanism of skin lesion production in decompression sickness are clear. Individual susceptibility varies. Ferris and Engel (1951) is a major source of information on this subject.

Transient blurring of vision and other visual disturbances occasionally accompany more serious manifestation of decompression sickness. Visual disturbances are probably secondary to vasomotor decompensation and shock and are rarely of CNS origin.

Central nervous system manifestations are probably the most serious consequence of inadequate decompression. The great variety of bubble formation sites yield a comparable variety of disturbances, sometimes bizarre, often multiple, and certainly unpredictable. Theoretically, bubble formation can produce almost any symptom. Damage may be extensive or confined to minute structures. Most CNS lesions occur in the spinal cord, particularly in the lower segment; cerebral damage is relatively rare. Quadriplegia, paraplegia, and paralysis of a single or several extremities in every combination have been reported. Early vasomotor collapse and shock are associated with the more serious manifestations. Various body organs and functions may be affected. Permanent residual damage may result in loss of bowel and bladder control and/or some degree of residual paresis in one or both of the lower extremities. Gersh and Catchpole (1951) summarize the findings on pathologic changes in the human CNS caused by decompression sickness.

Other manifestations include respiratory distress ("chokes"), headaches, nausea, and fatigue. The "chokes" is the rare but interesting symptom of delayed development of substernal distress, often described as burning. The condition is aggravated by deep inspiration and subsequent burning pain in all phases of respiration and an uncontrollable urge to cough. As the pain intensifies and spreads, respiration becomes difficult, coughing more severe. The victim becomes cyanotic, very apprehensive and progresses into clinical shock with subsequent loss of consciousness on occasion. The condition can be fatal if untreated. Headache, nausea, and fatigue generally are considered to be nonspecific reflex phenomena secondary to the conditions previously discussed. Marked fatigue, often out of proportion to the physical exertion expended, is frequently experienced following deep dives, particularly if the decompression has been marginal. The onset of fatigue is generally 2-5 hr after surfacing and is characterized by an overpowering urge to sleep. The underlying mechanisms responsible are not known; however, fatigue is frequently considered a minor manifestation.

Certain symptom patterns are evident. Study of case histories indicates that certain symptoms and anatomic sites are more frequently involved than others. Table 3-1 summarizes the frequency occurrence of the more common symptoms. Duffner et al. (1947) reported on the frequency of combinations of symptoms (Table 3-2). Symptoms may appear immediately after surfacing or more than 6 hr later (Table 3-3). Treatment for decompression sickness is discussed in Section 3.11.

SYMPTOM	FREQUENCY (%)
Local pain	89.0
Lower extremity (70%)	
Upper extremity (30%)	
Skin rash (with itching)	11.0
Visual disturbances	6.0
Motor paralysis or weakness	5.5
Vertigo	5.0
Numbness	4.8
Respiratory distress ("chokes")	2.4
Headache	1.9
Unconsciousness	1.5
Aphasia	1.2
Nausea	0.9

Table 3-1. Frequency of Symptoms Occurring in Decompression Sickness (Modified from Dewey [1962])

COMBINATION	FREQUENCY (%)
Single symptom only	70.0
Two symptoms	25.6
More than two symptoms	4.4
Pain as only symptom	68.0
Localized pain not symptom	5.3

Table 3-2. Frequency of Combination of Symptoms (Duffner et al., 1947)

INTERVAL AFTER SURFACING	OCCURRENCE OF INITIAL SYMPTOMS (%)
Within 30 min	50
Within 1 hr	85
Within 3 hr	95
Within 6 hr	99
Delayed more than 6 hr	1

Table 3-3. Interval Between Surfacing and Onset of Initial Symptoms (Modified from US Navy [1956])

The prevention of decompression sickness is best accomplished by observing the following rules established by the US Navy (1963) and supplemented by me:

1. *Careful selection of personnel:* Persons not properly trained in diving and the use of decompression tables and procedures are immediate candidates for a case of the "bends" and should be rejected. In addition, persons with old injuries and diseases which could result in abnormally restricted circulation should be rejected. In other words, divers must meet certain medical standards.

2. *Observation and evaluation of each man before he makes any dive:* Alcohol intoxication or "hangover," excessive fatigue, or a general run-down condition should be sufficient to temporarily restrict a man from diving activities. All of these conditions may enhance susceptability to decompression sickness. It is the responsibility of the divers, the diving officer, or the diving supervisor to restrict a diver when his physical condition is not satisfactory.

3. *Careful attention to details of the dive:* Establishment of a good dive plan with accurate depth and time determinations is mandatory. Never depend on SCUBA tank volume and air-supply duration as a measure of "no-decompression" limits. Table 6-2 readily illustrates that a SCUBA (open-circuit) diver can exceed "no-decompression" limits even when using a standard single cylinder (72 ft^3). All divers working below a depth of 30 ft should be equipped with a watch and depth indicator and/or automatic decompression meters. Keep accurate records of all dives, they may be important in diagnosis and treatment of decompression sickness.

4. *Strict observance of the decompression tables (or automatic decompression meter) with due consideration of modifying factors:* Adhere to the tables at all times unless there is reason to question the accuracy of depth or time. In this event, decompress the diver for a dive of greater depth and longer duration. Terminate dive if decompression meter malfunction is suspected and undergo conventional stage decompression if the "no-decompression" limits have possibly been exceeded. Also, take into account working conditions,

e.g., physical exertion, water temperature, etc., and lengthen decompression accordingly. When in doubt, always act in the diver's favor by adding to the decompression; never shorten decompression for mere convenience.

5. *Report all symptoms or signs immediately:* Serious cases of decompression sickness often begin with a slight pain or itch. Failure to treat promptly can result in serious permanent damage or at least prolonged treatment.

Dewey (1962) published an excellent paper giving a relatively complete discussion of decompression sickness. This work has been a major source for the previous discussion. For additional practical information, the reader is referred to the US Navy (1970 a) and Cross (1968). US Navy standard air decompression and repetitive dive tables are given in Appendix C.

3.7 OTHER COMPLICATIONS

3.7.1 Lung Infection

Several cases of lung infection have been traced to a fungus which grows in the hoses of regulators. This fungus is thought to be nourished by human saliva, and grows more readily in tropical climates. Divers have been hospitalized, and there are unverified reports of death from acute cases of lung infection. The fungus can be eliminated by soaking the hoses, mouthpiece, and nonreturn valves in a mixture of 2 oz of zephiran chloride and 1 gal. of water; should metal parts be soaked, add 16 antirust tablets to prevent corrosion. An alternate procedure (US Navy, 1970 a) is to scrub the hoses with surgical soap and rinse with a 100-ppm chlorine solution. A noncorrosive germicidal and fungicidal disinfectant should be used on metal parts; remove disinfectant before using equipment.

3.7.2 External Ear Infection

Ear infection or "fungus" may be considered an occupational disease of divers. The actual infection is usually contracted in contaminated or warm-climate waters due to bacteria similar to those which cause pimples and boils. To prevent infection, rinse ears with a 50-70 percent alcohol solution after diving to dry the ear canal. If infection develops, it is necessary to consult a physician for treatment.

Dr. S. H. Reuter (personal communication) recommends the following procedure for removing water from the ear canal and accelerating drying after swimming:

1. In a 4- or 6-oz bottle, place 1 tsp of white vinegar and fill with isopropyl (70 percent) rubbing alcohol.
2. Warm the solution by placing the bottle in a basin of hot tap water.
3. Lie on your side and fill the uppermost ear canal with the solution for 2-3 min.
4. Cover the ear with a folded towel and turn over so the towel absorbs the solution as it runs out of the ear.
5. Repeat the procedure for the opposite ear.
6. The alcohol solution may burn slightly. If it is painful or burns excessively, this means that the skin surface is broken and is a warning signal. Do not go swimming for 48 hr. After this period of time, try the solution again. If there is no burning, swimming is permitted.

3.7.3 Hyperventilation Syndrome

Hyperventilation initiated by anxiety and/or physical stress may result in unconsciousness or muscle spasms as possible consequences of excessive depletion of carbon dioxide with subsequent acid-base imbalance in the blood and body. The diver may not be aware of his pending problem. In the water this can result in drowning. Some individuals are more susceptible to low CO_2 tension (hypocapnia) than others; however, loss of consciousness and muscle spasms could probably be induced in almost anyone with sufficiently prolonged hyperventilation.

Both SCUBA and surface-supplied divers should be aware of the problems associated with hyperventilation. If the diver notices that he is involuntarily hyperventilating, he should take immediate steps to slow his breathing rate. A SCUBA diver should notify his buddy and, if feasible, promptly ascend. When he reaches the surface, he should inflate his lifejacket. Don't attempt to swim to the boat or shore unaided since unconsciousness may be imminent. A tender should continuously monitor the diver's breathing for signs of hyperventilation. If the diver starts to hyperventilate, he should be asked to stop work and rest. Holding his breath for short periods will aid in replenishing low CO_2 levels and possibly avert further complications. Drowning and the hyperventilation syndrome are discussed in detail by Prasser (1969).

3.7.4 Hyperpnea-Exhaustion Syndrome

Various problems in diving such as equipment malfunction, reaction to venomous marine animal wounds, cold stress, exhausting swims, etc. may cause a diver to panic. A frequent manifestation of panic is rapid, *shallow* breathing, resulting in insufficient ventilation of the lungs. Subsequently there is an accumulation of carbon dioxide in the lungs, blood, and body tissues (hyperpnea). The diver's situation is further complicated by possible decrease in buoyancy due to inadequate inflation of the lungs. The onset on the hyperpnea-exhaustion syndrome is indicated by rapid, shallow breathing; dilation of the pupils; inefficient swimming movements; and signs of exhaustion. The diver will experience anxiety and exhaustion. Collapse from exhaustion, unconsciousness, and subsequent drowning may follow. Divers exhibiting the signs or symptoms of this manifestation should immediately terminate dive, surface, drop weight belt, and inflate lifevest. Tenders and diving partners should watch for signs of distress. This condition is probably responsible for many problems and near drownings while the SCUBA diver is swimming on the surface.

3.7.5 Overexertion and Exhaustion

Nearly everyone has experienced the "out-of-breath" feeling, from working too hard or running too fast. It is possible for a person to exceed his normal working capacity by a considerable margin before the respiratory response to overexertion is apparent. The end result is generally shortness of breath and fatigue. On land, this presents little problem.

Underwater (under increased ambient pressure), the problem of exertion is modified by several factors and is considerably more serious. Even the finest breathing apparatus offers some resistance to the flow of air. As the depth increases, so does the density of the air, and consequently, it moves through the body's air ways with greater resistance to flow.

When shortness of breath and fatigue are brought on by overexertion, the diver may not be able to get enough air. The feeling of impending suffocation is far from pleasant, and it may lead the inexperienced diver to panic and a serious accident.

Man's ability to do hard work underwater has definite limitations, even under the best of conditions. Many situations can lead to exceeding these limits. They include

- working against strong currents;
- prolonged heavy exertion;
- wasted effort;
- breathing resistance, especially with poorly designed and maintained breathing apparatus;
- carbon dioxide build-up;
- insufficient breathing medium, contamination;
- excessive cold or inadequate protection.

The diver will realize that he has overexerted himself by labored breathing, anxiety, and a tendency toward panic that accompanies the overexertion feeling.

If the diver feels the typical "air hunger" and labored breathing starting to appear, he should do the following:

- Stop, rest, and ventilate to get a maximum flow of air by holding the SCUBA mouthpiece in place and pushing the purge button on a single-hose unit, or with a double-hose unit, turn on his back to obtain a free flow of air. Breathe deeply. Ventilate helmet or mask with free flow.

- Inform his "buddy" or tender.

- Do not shoot to the surface--terminate dive with a slow, controlled ascent.

- When he reaches the surface, he should inflate his life preserver and return to the boat or shore, or if too exhausted, signal for an immediate "pick-up."

The "buddy" and surface crew should

- render all possible assistance;

- watch for signs of panic that might lead to a serious underwater accident;

- help diver aboard;
- provide rest, warmth, and nourishment.

Overexertion can be prevented if the individual knows and observes his limitations, takes into consideration the working conditions, and sets up the diving operation accordingly. For example, plan the dive so that you can move with the current and not against it. Diver's should keep themselves in excellent physical condition. The equipment must also be in top working condition. Be alert for signs of fatigue!

3.8 Additional Information

For further information on the physiology and medical aspects of diving, the reader should consult US Navy (1970 a), Dueker (1970), Greenbaum and Hoff (1966), Lambertsen (1967), Lambertsen and Greenbaum (1963), Hoff and Greenbaum (1954), Bennett and Elliott (1969), Goff (1955), Miles (1962), and the Committee on Hyperbaric Oxygenation (1966). Psychological aspects of diving and living underwater are discussed by Radloff and Helmreich (1968).

3.9 Basic First-Aid Procedures

First aid is the "immediate and temporary care given the victim of an accident or sudden illness until the services of a physician can be obtained (American National Red Cross, 1957). Proper first aid can make the difference between life and death. Every diver and person related to diving operations should have a good knowledge of first aid. An American National Red Cross first-aid course or equivalent is recommended. The following is a brief reminder of some vital aspects of first aid particularly applicable to diving-related accidents as given by the US Navy (1963, 1970 a), the American Medical Association (1967), and the American National Red Cross (1957).

3.9.1 General

If the nature of the injury is uncertain, immediately check the victim for respiration (rate and type), bleeding, head injury, or broken bones. The first objective is to save life by: (1) preventing heavy loss of blood, (2) maintaining breathing, (3) preventing further injury or contamination of wounds, (4) preventing shock, and (5) sending for a physician. The first-aider must avoid panic, inspire confidence, and do no more than necessary to sustain life until professional help arrives. Obtain the services of a physician in all but minor, uncomplicated wounds or burns. Never release a victim that has been unconscious without first having the victim examined by a physician.

3.9.2 Control of Heavy Bleeding

If bleeding is heavy, from wounds to one or more large blood vessels, this must be stopped before anything else is done. Such heavy loss of blood can result in death in 3-5 min. Immediately apply pressure directly over the wound with dressing, clean cloth, hand, or fingers. Secure dressing with bandage or cloth strips and elevate bleeding part higher than the rest of the body unless bones in the part are broken. Keep the victim lying down. Take shock prevention measures. Administer liquids (water, tea, coffee) if the victim is conscious and can swallow. Do not give the victim any alcoholic beverages. Do not give the victim any liquid at all if he is unconscious or if abdominal injury is suspected.

Use a tourniquet only for an amputated, mangled, or crushed limb or profuse bleeding that cannot otherwise be controlled. Use only a wide, strong piece of cloth. Wrap tourniquet around upper part of limb above wound. Tie with an overhand knot, place a short stick on the knot, and secure with a square knot. Twist stick just tight enough to stop bleeding. Once the tourniquet has been applied, leave it in place until immediate, qualified, surgical, and support measures can be applied by medical personnel. Keep under constant observation and mark "TK" on the victim's forehead. Do not cover tourniquet.

3.9.3 Artificial Respiration

If the victim is apparently not breathing or the lips, tongue, and fingernails become blue, start artificial respiration immediately; seconds count. When in doubt, begin artificial respiration, since little or no harm can result from its use, and delay may cost the victim's life. *Mouth-to-Mouth breathing* is generally considered the best method since it can be performed in a number of positions, including in the water or in cramped surroundings;

requires no special equipment; is not fatiguing for the first-aider; and allows the first-aider greater control of a procedure.

Proceed as follows:

- Quickly check mouth and throat for obstructions. Remove vomitus, mucus, etc. with a cloth or index finger. Tilting the head and body to the side is helpful.
- Turn victim on his back.
- Lift victim's neck with one hand and tilt his head by holding the top of his head with your other hand. If necessary, pull the chin up so the tongue doesn't fall back to block the airway.
- Close the nose by pinching with fingers.
- Take a deep breath and place your mouth over the victim's mouth, making an air-tight seal.
- Blow rapidly until the chest rises--forcefully into adults and gently into children.
- Remove your mouth and let the victim exhale while you take another breath.
- Repeat inflation of the lungs 12-20 times per minute until the victim is pronounced dead or regains breathing. *Do not give up!*

3.9.4 Prevention of Shock

Shock is a serious complication in almost any injury, severe illness, or emotional upset. Signs of shock include: (1) cold, moist skin; (2) paleness; (3) chilling; (4) nausea or vomiting; (5) shallow breathing; and (6) weak, rapid pulse. Prevent or treat as follows:

- Keep victim lying down with head slightly lower than the rest of the body (except if head injury is suspected or this position causes breathing difficulties).

- Keep victim warm by covering.

- If conscious, able to swallow, not vomiting, and has no apparent abdominal injury, give liquids (water, tea, coffee, etc.; never alcoholic beverage). Give shock solution (1 qt water, 1 tsp salt, 1/2 tsp baking soda) if available.

- Keep victim calm and reassured.

3.9.5 Minor Wound

Small cuts and abrasions are common for divers. Infection is the principal danger in small wounds, so any break in the skin must be protected. Do not touch a wound with your fingers or allow cloths to touch it. Keep it clean. Do not use an antiseptic on the wound. Immediately cleanse the wound and surrounding area with soap and warm water, wiping away from the wound. Hold a sterile pad firmly over the wound until bleeding stops. Apply a clean dressing and secure with a bandage. Bandaids may be used for small wounds.

3.9.6 Burns

Burns result from heat or chemicals. Any burn, including sunburn, may be complicated by shock and the victim must be given first aid for shock. Place the cleanest available material over all burned body areas to exclude air. Consumption of nonalcoholic liquids by the victim is beneficial if possible. Transport victim immediately to hospital for severe burns. All burns, except where skin is reddened in only a small area, should be seen by a physician. *Do not* apply ointments, grease, baking soda, or other substances to extensive burns.

3.9.7 Head Injury

It is difficult to discover internal injury to the head. Suspect a brain injury if the person loses consciousness; has blood or fluid escaping from the ears or nose; has a slow pulse, head ache, convulsions, different size eye pupils; or is vomiting. It is necessary to keep the victim lying down and under close observation. Do not place the head lower than the feet. If the victim is unconscious, remove false teeth or objects that might cause choking. Do not move if there is bleeding from the nose, mouth, or ears. Control bleeding from a head wound by applying a pressure dressing. Use common sense in regard to using pressure over a possible skull fracture.

3.9.8 Convulsions

Do not attempt to restrain or douse victim with water. Remove objects that might injure victim, or in close quarters, surround with padding (pillows, air mats, blankets, etc.). Don't place a finger or hard object between the teeth.

3.9.9 Injury to Spine or Neck

If possible, do not move victim or allow victim to move without proper stretcher and professional assistance. If the victim must be removed from the water and a neck or head injury is suspected, support victim, taking care not to move the head, neck, or back. Place a stiff, wide board under victim and secure with straps. Keep head level and under slight tension. Do not let it drop forward. Keep victim warm and quiet until professional assistance is available.

3.9.10 Fractures

Do not move a person with suspected fracture until it has been splinted unless the victim is in imminent danger. Place the limb in as natural a position as possible without causing discomfort. Apply splints which are long enough to extend beyond the joints above and below the fractured area. Any firm material can be used. Inflatable splints are excellent. Secure splint at a minimum of three sites: (1) above the joint above the fracture, (2) below the joint below the fracture, and (3) at the level of the fracture. If the fracture is open, apply a pressure dressing to control bleeding and prevent contamination, and splint *without* trying to straighten the limb or return it to natural position.

3.9.11 Heat Exhaustion

A person suffering from heat exhaustion has pale and clammy skin, rapid and weak pulse, weakness, headache, nausea, and possibly, cramps in the abdomen or limbs. The victim should be kept lying down with his head level or lower than the rest of his body. Move him to a cool place; however, protect him from chilling. Give the victim salt water (1 tsp salt to 1 qt water) if he is conscious.

3.9.12 Heat Stroke

A heat-stroke victim will have flushed, dry, and hot skin, rapid and strong pulse, and is often unconscious. Cool the body by sponging with cold water or by cold applications and if the victim is conscious, give him salt water (1 tsp salt to 1 qt water).

3.9.13 Frostbite

As frostbite develops, the skin changes from a pink color to white or greyish-yellow. Initial pain quickly subsides and the victim will feel cold and numb. Generally, he is not aware of frostbite. Cover the frostbitten area with a warm hand or woolen material. If the fingers or hands are frost-bitten, have the victim hold his hand next to his body, in his armpits. Get the victim to a heated area as soon as possible and place the frostbitten part in warm water (108° F). If this is impractical, gently wrap the area in blankets. *Do not rub* with snow or ice; let circulation return naturally. When the part is warmed, encourage the victim to exercise fingers and toes. *Do not use hot water, hot-water bottles, or heat lamps on the frostbitten area.*

3.9.14 Snakebite

Poisonous snakebites must be dealt with immediately. Except for the coral snake, in the United States poisonous snakebites can be recognized by the presence of two distinct punctures caused by fangs. Swelling occurs rapidly and the skin becomes dark purple in color. Lay victim down immediately and apply a constricting band around the arm or leg above the bite if the bite is on a limb. Tighten the band just enough to make veins stand out prominently under the skin without causing the pulse to disappear below the band or causing a throbbing sensation. Keep the victim absolutely quiet and transport immediately to a physician. Apply ice over the bite if possible. If there is to be considerable delay between occurrence of bite and treatment, make a crosscut (approximately 1/4 in. long and 1/4 in deep) over each fang mark to encourage free bleeding. Apply suction by mouth or suction device; continue for at least 1 hr. After the first hour, the band may be loosened for approximately 1 min every 30 min. The victim may administer first aid to himself.

3.10 Diving Accidents: Recognition and First Aid

Probably the most serious mistake in dealing with diving accidents is the failure to recognize air embolism or decompression sickness. In many incidences these may be indistinguishable from each other; however, they both require the same first-aid measures and recompression. In the more serious situation, although permanent damage of some degree can be expected in all untreated cases, death is generally the consequence of failure to recompress. Regardless, air embolism or decompression sickness must at least be considered in diagnosis of almost any abnormal sign or complaint presented by a person who has been underwater *with breathing apparatus*.

Unconsciousness, during or following a dive, presents a particular problem of diagnosis and management; however, one practical rule can be given: an unconscious diver must be considered a victim of air embolism or decompression sickness until proven otherwise by medical personnel. These conditions can coexist with seemingly more obvious causes of unconciousness such as apparent or "technical" drowning (Bond, 1965) and injury to the head. Spontaneous recovery doesn't rule them out if neurologic defects remain.

Respiratory arrest from any apparent cause must also be managed the same as unconsciousness if the victim has been using underwater breathing apparatus. However, obviously the standing rule for first aid if the diver is not breathing must be to administer artificial respiration *immediately* and continue while the victim is being transported to a recompression chamber, has regained natural breathing, or has been pronounced dead by medical personnel. All divers and personnel connected with diving operations must know how to apply mouth-to-mouth artificial respiration. Using a lifejacket or float, artificial respiration can be administered while the diver is still in the water and being returned to the base of operation. A mechanical resuscitator has advantages. However, do not wait for the resuscitator, start manual artificial respiration immediately while the resuscitator is being brought to the scene and readied.

Neurologic disorders short of unconsciousness must likewise be considered as resulting from air embolism or decompression sickness in almost every case. Nearly the entire spectrum of central or peripheral nervous symptom involvement manifestations can be produced or simulated by these conditions. Air embolism nearly always manifests itself during ascent or within a few minutes after surfacing, and the symptoms are usually major. Decompression sickness, however, may become evident many hours after the dive and may involve anything from minor local defects to unconsciousness and convulsions.

Bloody froth, coughed up or seen at the nose or mouth, signifies lung injury. When a diver using underwater breathing apparatus exhibits this symptom, particularly if associated with neurologic disorders, he is probably a victim of air embolism. In breathhold diving, bloody froth generally indicates thoracic squeeze.

Unconsciousness, respiratory arrest, neurologic disorders, and certain associated manifestations are indicative of air embolism. Symptoms are dramatic and sudden in onset, and brain damage or death can result in a matter of minutes; recompression is the only proper treatment. However, in applying first aid, Kruse (Bohmrich, 1965) observed dramatic relief from symptoms of air embolism when he placed a victim in a 15-degree, head-down position. Atkinson (1963) conducted a series of experiments with laboratory animals in which he injected emboli and tilted the animals in a 15-degree, head down position. This technique was successful in increasing intravenous pressure, dilation of the venous system and capillary bed of the brain, dislodgement and dispersion of emboli, and restoration of circulation. *The tilt-table technique is not considered as a substitute for recompression,* but as a slight modification of the standard position used in first aid for a victim of shock. The resultant intracranial vascular pressure increase may be paramount in the prevention of permanent brain damage. Atkinson (1963) states, "In view of the serious consequences of the neurologic manifestations of air embolism, the supine Trendelenberg position (15 degrees, head down) might be considered as a first-aid measure until recompression can be accomplished." The victim is kept in this position while enroute to a recompression facility, and resuscitation may be accomplished in this position if necessary. Based on laboratory experimentation, the 15-degree tilt appears preferable. Mediastinal and subcutaneous emphysema and pneumothorax are often associated with air embolism. If symptoms of these conditions are indicated, consider the diver as a victim of air embolism and take appropriate first-aid measures.

Damage to the ears and sinuses can result in local pain, hemorrhage, and subsequent infection. Most submarine medical officers conclude that a strict "hands-off" policy results in fewer complications and more rapid healing. Seek medical attention if drainage, tenderness, and infection persist.

The primary first-aid procedure for respiratory problems (anoxia, CO_2 excess, CO poisoning, near drowning, and oil-vapor inhalation) is breathing fresh air. If breathing has ceased, start artificial respiration immediately. All victims must receive first aid for shock, and medical attention even if the victim is revived without medical assistance. Carbon monoxide victims must be treated with oxygen, preferably under increased pressure (recompression). Oil-air vapor inhalation victims may be retained for medical observation.

The proper action for almost all diving casualties can be summarized in four simple statements (US Navy, 1970 a):

1. If the diver isn't breathing, start artificial respiration immediately.
2. Acquire medical attention at once (unless the injury is a mild or simple condition).
3. If the diver is injured, give appropriate first aid (combat shock; Trendelenberg position).
4. If there is any possibility of air embolism or decompression sickness, arrange for immediate transportation to a recompression facility.

3.11 Recompression and the Recompression Chamber

It is absolutely essential that a victim of decompression sickness or an air embolism be treated by recompression as soon as possible following the appearance of symptoms. In cases of decompression sickness prompt and adequate treatment will generally preclude the development of residual damage. It is well established that the incidence of slow or incomplete response to treatment and the magnitude of residual damage are directly proportional to the length of time between the first appearance of decompression sickness symptoms and the beginning of recompression procedures (Dewey, 1962). In cases of air embolism, the brain is frequently involved; when it is, the symptoms are usually extremely serious and unless the victim is recompressed immediately, death or permanent residual damage may follow a delay of 1-2 min (US Navy, 1970 a). Transportation to the nearest facility equipped with a recompression chamber must be by the most rapid means available. When the distances are great, an ambulance is generally not the most rapid transportation available. Under such circumstances, efforts should be made to obtain a helicopter or other airborne conveyance. Flight at a low altitude will not appreciably aggravate the victim's condition and is of minor consequence when the alternative is delay (Dewey, 1962).

All the technical and theoretical details of treatment by recompression will not be reiterated here. Complete and authoritative discussions are available in reports by the US Navy (1970 a) and Lanphier (1966). Lanphier points out that the purpose of recompression is to provide prompt and lasting relief from symptoms of decompression sickness and air embolism. Recompression procedures are designed to reduce the bubbles to a size at which they become asymptomatic and to ensure that no bubble becomes symptomatic upon subsequent decompression. Procedures must be such that no new bubbles form in the process. Proper treatment must be conducted under the auspices of specially trained personnel. Improper or inadequate attempts by untrained personnel to recompress a victim may result in even more severe damage than the initial manifestations.

There are a number of important considerations in the application of recompression treatment to decompression sickness. It is important to treat even doubtful cases, since failure to treat can result in serious complications. As previously stated, the recompression must be prompt, since delay further complicates treatment and recovery. Recurrence of symptoms is not uncommon, even during or immediately following properly prescribed treatment (Rivera, 1964; Goodman, 1967). Consequently, the treated victim should remain near a treatment facility for at least 24 hr following treatment.

Appendix C contains the various treatment schedules currently used by the US Navy (1970 a). Clearly, more serious manifestations require compression to a greater depth and an extension of the time required for treatment. Oxygen is used at shallower depths to reduce the alveolar pN_2 to the lowest possible level, thus creating a "steeper" gradient across the alveolar membrane to enhance the diffusion of gas.

The reason victims of decompression sickness or air embolism are not compressed to depths greater than 165 ft to even further reduce the size of offending bubbles becomes clear if one considers the fact that the diameter, not the volume, of the bubble is the critical dimension governing symptom development. Whereas the volume is inversely proportional to the absolute pressure, the diameter is inversely proportional to the cube root of twice the pressure. Consequently, recompression to 165 ft reduces the bubble volume to one-sixth of its surface value; however, it only decreases the diameter of the same bubble by a factor of 1/3.35. Recompression to a pressure equivalent to 858 ft only reduces the diameter by a factor of as much as 1/5. Clearly, recompression to depths greater than 165 ft offers little more than additional complications.

There is an increasing awareness of the incremental frequency with which difficulties are encountered in recompression treatment of severely injured divers and the grossly inadequate decompression now characterizing civilian diver casualties. Earlier US Navy recompression procedures were, in general, reliable for treatment of "pain only bends" subsequent to exposures conducted in accordance with the US Navy (1970 a); however, they were adequate in the treatment of severe decompression sickness following grossly inadequate decompression from compressed-air dives. Goodman and Workman (1965) and Goodman (1967) reviewed this situation and developed and evaluated alternative therapeutic approaches to the treatment of decompression sickness. The studies resulted in the development of the "Minimal-Pressure, Oxygen Recompression Treatment for Decompression Sickness" tables (Appendix C). Goodman and Workman believe that the current US Navy treatment tables should be retained with oxygen recompression procedures alternatively available. Goodman (1967) indicates that the new minimal-pressure oxygen approach has consistently afforded prompt, complete, and lasting relief in severe decompression sickness. The minimal-pressure oxygen approach is also indicated for air embolism victims; however, initial treatment depth is 165 ft compared to 60 ft for decompression sickness (US Navy, 1970 a).

The length of time has been significantly reduced. Prior to the development of the new US Navy procedures, treatment of air embolism required 18-38 hr in a recompression chamber, providing there were no complications or recurrence of symptoms. Recently, Waite et al. (1967) conducted experiments with animals to determine if alternate procedures might be feasible. They found that maximum effects of recompression were observed between 2 and 4 atm absolute. However, at present there is insufficient evidence to say that the maximum pressure of 165 ft (6 atm absolute) should be considered as unnecessary.

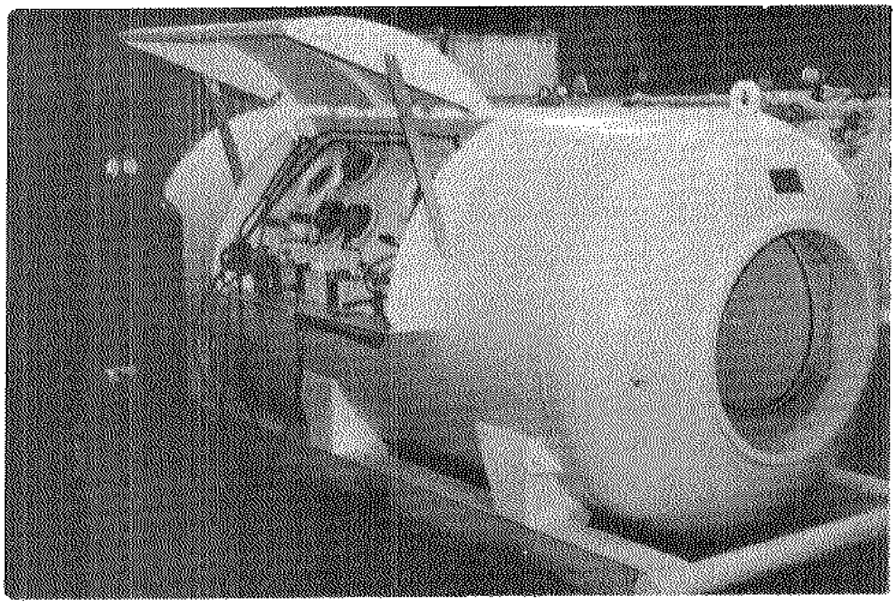
Waite et al. (1967) also found indications that prolonged recompression, as in Tables III and IV of the US Navy standard treatment tables (Appendix C), is not necessary to effectively treat cerebral air embolism. All successful treatment runs in this series of experiments consisted of bounce dives to 165 ft for less than 10 min and return to the surface at 60 ft/min with a 2-min stop at 10 ft (170-ft table). This procedure *is not* yet prescribed for treatment of air embolism in humans and is not to be used as an alternate to standard US Navy (1970 a) procedures.

Emergency procedures for handling diving accidents that require recompression in the Michigan area are given in Appendix D. A detailed list of recompression chambers has been published by the US Navy (1971) and Kindwall et al. (1971).

Recompression in the water without a chamber is not recommended because it is extremely hazardous and difficult. Divers have been recompressed using a deep-sea diving rig as a substitute for a chamber; however, the US Navy (1970 a) considers this means only in a "grave emergency." The deep-sea rig does offer some protection and a nearly inexhaustible air supply. Any attempt to recompress a diver underwater using SCUBA is invariably dangerous and, almost without exception, futile. Inadequate treatment of air embolism and decompression sickness is frequently worse than none (Lanphier, 1957). Possibly, future medical research and the development of sophisticated SCUBA will open new avenues of practical field treatment of less complicated cases. However, at present, all suspected victims of air embolism or decompression sickness must be transported to an approved recompression facility without delay.

The layman is cautioned against attempting to administer recompression. Such action without supervision by a licensed physician can involve risk not only of harm to the victim but may involve legal complications, both civil and criminal.

A *recompression chamber* (Figure 3-4) is a chamber in which a diver may be put back under pressure for treatment of decompression sickness or air embolism or for surface decompression procedures. The chamber is generally constructed of metal and has a working pressure of at least 75 lb/in^2. Maximum working pressure capability and size will depend on mission requirements. A double-lock chamber with two separate compartments capable of being pressurized



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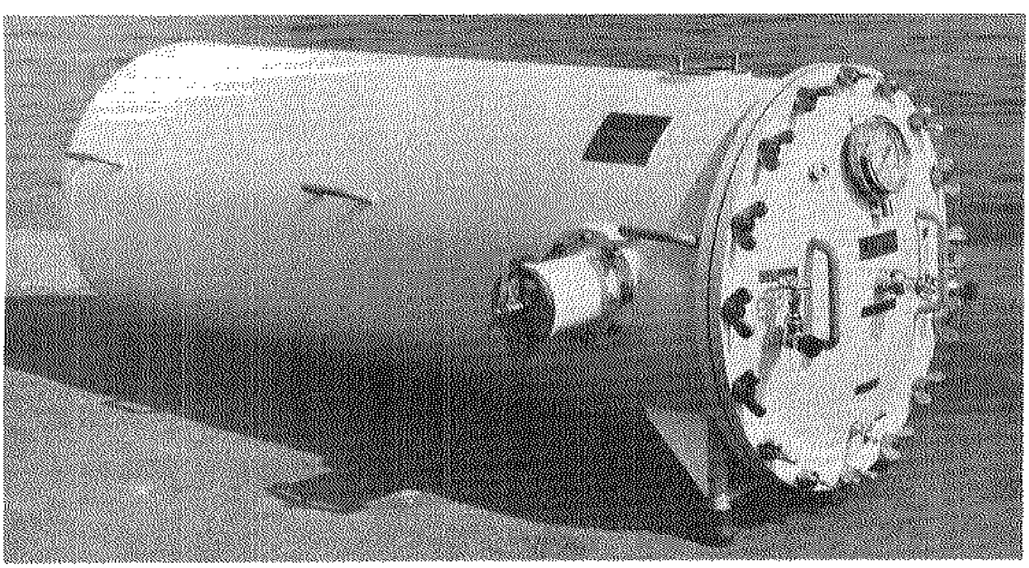

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Figure 3-4. Recompression Chambers: (a) Double-Lock, 54-in. Diameter Recompression Chamber Commonly Used for Offshore Oil Diving Operations (Photo by Somers); (b) Single-Lock, 30-in. Diameter, Portable Recompression Chamber (Photo Courtesy of SCUBAPRO).

independently and enough space to accommodate two divers and an attendent in the main compartment is recommended. Double-lock chambers generally have an inside diameter of 48 in. or more. The chamber should be equipped with oxygen breathing equipment which is designed to prevent excessive accumulation of oxygen in the chamber. The air and oxygen supply system will depend on the installation, size, and type of chamber.

Small, portable chambers are not commonly used by the US Navy and the commercial diving industry. However, they may have value when no other chamber is available and diving activity is conducted at a great distance from a larger chamber. The US Navy (1970 a) indicates that even if the chamber is so small that it only accommodates a single victim, it is far better than no chamber at all. The value of the portable chamber is increased if it is designed to facilitate transfer under pressure to the nearest larger chamber.

For further information on design specification and operation of recompression chambers, consult US Navy (1970 a). Information on general requirements for materials certification in hyperbaric facilities is given by the US Navy (1970 b).

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4 DIVING PROCEDURES

4.0 Diving Procedures

Diving procedures is a subject that is frequently ignored in sport diving manuals, which are used for many research diving training programs. Since research diving operations must be conducted at the highest possible level of efficiency and safety, it is necessary that all personnel have a knowledge of standard operational procedures. The basic procedures given in this chapter are modified from US Navy (1970) for compatibility with research diving operations.* Also included in this chapter are decompression procedures and cold-water diving techniques and equipment.

4.1 Personnel

4.1.1 Diving Supervisor

The diving supervisor should hold a diver's certificate that is valid for the depth at which diving operations are being conducted and should be qualified in the use of all equipment used in the diving operation for which he is supervisor.

The diving supervisor is in complete charge of a particular diving operation at the scene. His primary function is to plan, organize, and manage the diving operation. He is responsible for maintaining safety standards and must not tolerate violations of accepted diving procedures and standards. On major operations, the diving supervisor will generally not enter the water. His usual post is on the surface, where he is in full command of surface personnel and in a position to direct tenders and stand-by divers in an emergency situation. In order to utilize diving capabilities to maximum efficiency, an individual with proper qualifications may temporarily assume diving supervisor responsibilities while the actual person is working as a diver. However, it is absolutely necessary that a diving supervisor be in charge at the surface during all major diving operations. He should not be burdened with added responsibilities such as tending, timekeeping, communications, etc. On simple and limited diving operations, particularly when using SCUBA, the diving supervisor may also assume responsibilities as a diver and team leader.

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* Somers (1971) gives the diving operation regulations and procedures used at The University of Michigan.

4.1.2 Diving Teams

A SCUBA diving team must consist of no less than two divers. Diving alone should not be permitted, and all team members must hold a valid diving certificate. A leader will be designated for each diving team prior to entering the water, and it will be the responsibility of the other divers to stay in visual or physical contact with the leader. If a diver becomes separated, he should promptly surface or return to a previously designated location.

A diving supervisor will be designated for each diving operation. His qualifications and responsibilities are in accordance with those previously described.

The tender must be qualified to independently tend divers and operate all surface-support equipment. He may be trained in theory and operational aspects by the divers and diving supervisors. Ideally, tenders should be previously trained by instructors and assigned to diving operations by the diving supervisors. A tender-assistant may assume tender responsibilities when under the direct supervision of fully qualified diving and tending personnel. He may receive instruction in proper tending procedures during field operations. A tender should be assigned to be a communications man, timekeeper, record keeper, and diver's assistant.

It is recommended that one qualified person shall be designated as a "stand-by" diver and should be ready to enter the water promptly in the event of an emergency. The stand-by diver may accept tender responsibilities in routine operations; however, in more complicated diving operations the stand-by diver must be free from all other duties.

A surface-supplied diving team (deep-sea, lightweight helmet, shallow-water mask, hookah, etc.) should consist of a certified diver and tender. When a surface-supplied diver is required to work under obstacles or when there is a possibility of entanglement, a stand-by diver should be ready to enter the water promptly in the event of an emergency. For all dives in excess of 60 ft, it is highly recommended that a stand-by diver and a tender be prepared to commence operations within 1 min.

4.2 Preliminary Dive Planning

Preliminary planning is vital for the success of any diving operation. Without adequate preparation the entire diving operation may fail and, even more seriously, the safety and well-being of the divers may be jeopardized. The diver must be placed on the job under optimum conditions, including sufficient knowledge, training, experience, equipment, and safety. Surface support must be capable and well organized. Although the diving supervisor is responsible for preliminary planning and organization, the diving team and ship's crew must render all possible assistance.

The preliminary planning phase of a diving operation is divided into the following steps:

- survey of mission or task,
- evaluation of environmental conditions,
- selection of diving techniques,
- selection of divers and assignment of job,
- selection of equipment,
- fulfillment of safety precautions,
- establishment of procedures and briefing of personnel.

4.2.1 Survey of Mission or Task

The first step in planning a diving operation is to assess the mission or task and to formulate a general approach. It should be determined if the job is feasible and if the proper equipment and personnel are available to undertake the job. All factors that might constitute a specific hazard should be noted.

4.2.2 Evaluation of Environmental Conditions

Diver safety, especially for self-contained divers, is influenced considerably by environmental conditions. Careful consideration must be given to both surface and underwater conditions and appropriate arrangements made for diving under these conditions. Surface conditions to be considered include sea state, weather (present and predicted), tides, currents, ship traffic, etc. Underwater conditions include depth, bottom type or condition, visibility, and temperature.

Weather conditions will generally be the first factor to consider in planning a dive. When possible, diving operations should be cancelled or delayed during bad weather. Generally, rough seas can be expected during storms and high winds. Weather forecasts must be reviewed to determine if proper weather conditions will last for a sufficient amount of time to complete the mission. Critical weather changes and a wind shift can jeopardize safety of personnel and vessels. Conditions must be such that adequate mooring may be maintained for the duration of the operation.

Do not attempt self-contained or surface-supplied diving in rough seas (Sea State 4: 5- to 8-ft waves), and when possible, avoid or limit diving in moderate seas (Sea State 3: 3- to 5-ft waves). Naturally, sea-state limitations will be dependent to a large degree on the type and size of diving vessel. Diving operations may be conducted in rougher seas from properly moored, larger vessels or fixed structures. Land-based, self-contained divers should avoid entering the ocean in heavy surf.*

Current and tidal conditions must be considered before commencing with diving operations. Current direction and magnitude are important considerations when mooring a diving vessel. When currents exceed 1 knot, self-contained diving operations should be avoided unless adequate provisions are made for a diver pick-up boat to operate down current. Also, divers should carry smoke flares. Heavily weighted, surface-supplied divers are frequently required for work in currents. Tidal currents may prohibit diving at some locations except during periods of tidal current direction change. Consult tide tables when necessary and determine magnitude of tidal currents prior to diving.

Self-contained diving operations should not be conducted during periods of low visibility (fog, snow, rain, etc.). Self-contained divers are particularly vulnerable during periods of low visibility since they may lose orientation and be unable to relocate the diving vessel or shore base. Also, the diving vessel may be in danger when anchored during periods of limited visibility. Surface-supplied diving is permissible under limited surface visibility conditions, providing the diving vessel can safely anchor.

Ship traffic may constitute a hazard to divers, particularly self-contained divers. It is necessary to display proper visual signals in a prominent location on the diving vessel during operations in order to notify approaching vessels that divers are in the water. The following signals are appropriate:

- American Diver's Flag: This is a red flag 4 units wide by 5 units long with a one-unit wide white diagonal from the upper-left to lower-right corners. Sizes are not standardized and will vary with the size of the vessel.

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*Entry through surf will be discussed in another chapter.

- International Code of Signals: The two-letter signal "HD" has the meaning, "I am engaged in submarine survey work; you should keep clear."

- NATO Navies, Flag Numeral 4: This flag (a red flag with a white St. Andrew's Cross) flown alone means, "Divers or friendly underwater demolition personnel down."

- Underwater Task Shapes: A "red ball - white diamond - red ball" shape display spaced 6 ft apart may denote diving operations.

- United Nations Maritime Group International Divers Flag: The single-letter signal "A" or alfa flag (blue and white) is recommended for international waters and is currently used by the US Navy and the major nations of the world.

Self-contained divers must tow a float on which a diver's flag is displayed or be accompanied by a chase boat with a diver's flag if they operate out of the immediate vicinity of the support ship. The flag must be 3 ft above the water.

Diving personnel must be protected from excessive *exposure to adverse surface weather conditions.* When working in tropical areas, the staging area should be shaded to prevent overexposure to sun. During cold weather in northern waters, divers and surface personnel must be protected from cold air temperatures and wind. Divers should not be expected to dress in an open, unprotected vessel. When working from small craft, divers should dress prior to leaving the shore base. If under-ice dives are required, dress in heated, shore facilities or *heated*, portable structures on the ice. Do not submit divers to excessive exposure prior to the dive. Heated quarters and warm showers should be available immediately after surfacing.

The selection of diving dress and equipment will depend on the mission, weather conditions, and type of vessel. For example, even though water temperatures may permit the use of wet-type suits, cold air temperature and wind would dictate a variable-volume dry suit (or equivalent) when diving from an open or unheated vessel. In addition, double-hose regulators should be used with open-circuit SCUBA for diving in extremely cold weather and water.

The *type of bottom* affects the diver's ability to work and is a factor in determining visibility. Consequently, this must be considered in the preliminary dive plan and certain precautionary measures may be necessary to ensure the diver's safety and efficiency. *Mud* (silt and clay) bottoms are generally the most restrictive for divers. The slightest movement will stir sediment into suspension and restrict the diver's visibility. The diver must orient himself so that the current, if any, will carry the suspended sediment away from the work area, and he must use a distance line. Since the self-contained diver is more hampered by the limited visibility, surface-supplied diving techniques should be considered for work. For general survey work, self-contained diving techiques have certain advantages. The diver can weight himself to be neutral at survey depth and move about without touching the bottom.

Sand bottoms present little problem for divers. Visibility restrictions from suspended sediment are less and footing is firm. In marine areas the diver must be alert for sting rays buried in the sand.

Coral reefs are solid with many sharp protrusions. The diver should wear gloves and coveralls or a wet suit for protection if the mission requires considerable contact with the coral. Survey divers and photographers have to be cautious to avoid injury. Learn to identify and avoid corals and any marine organisms that might inflict injury.

Water depth is a basic consideration in the selection of personnel, equipment, and techniques. When possible, determine the depth accurately prior to diving and plan the dive duration, air requirements, and decompression schedule accordingly.

Water temperature is a major factor to be considered in dive planning since it will determine the type of equipment (diving suits) and, in some cases, the practical dive duration. Cold-water diving procedures and equipment are discussed later.

Underwater visibility depends on locality, water conditions, season, bottom type, weather, and currents. Dark or murky water is a disadvantage in all underwater operations. Self-contained diving should be avoided under zero to limited visibility conditions when possible and a surface-supplied diver used. If self-contained divers must work in limited visibility water, a "buddy" line is recommended.

Self-contained divers are at a considerable disadvantage, especially if decompression is required. In addition to a descent (shot) line, a distance line carried on a reel is required. This enables the divers to return to the shot line for controlled ascent. Short distance lines are also desirable for surface-supplied divers in limited visibility. An alternate method of controlling ascent and decompression is by the use of an inflatable float with a line marked at 10-ft intervals below the float and which is twice as long as the diving depth. At the end of the dive, the diver releases the float and secures the line to an object on the bottom with a releasable knot. He may then ascend to the appropriate decompression level, unreeling the remaining line below him. When he surfaces, the diver simply tugs on the free end of the line to release the knot and to retrieve the line.

Self-contained divers must establish a procedure for reunion of separated divers. Generally, the best procedure is to surface or return to a predetermined bottom location if separated. Striking the SCUBA cylinder with a rock or knife has only limited value in reuniting separated divers.

4.2.3 Selection of Diving Techniques

The proper diving technique, SCUBA or surface-supplied, is based on the mission requirements, environmental conditions, and available personnel. It is the responsibility of the diving supervisor and divers to review the situation and determine which technique to use. The advantages and limitations of various techniques are discussed in respective chapters.

4.2.4 Selection of Divers and Assignment of Jobs

The diver must be qualified and designated in accordance with the depth and equipment rating required for the mission (consult Somers [1971] for diver rating). The diving supervisor is responsible for determining the qualifications of a diver before assigning him to a mission. In addition to the diver, the diving supervisor must designate qualified tenders, timers, and stand-by divers.

4.2.5 Selection of Equipment

The diving supervisor and divers will determine whether to use SCUBA or surface-supplied diving equipment for a particular mission based on a review of the mission requirements, personnel available, and environmental conditions. The diver must be outfitted with the proper equipment to complete the mission or task assigned. Minimum equipment requirements for self-contained and surface-supplied divers are in respective sections of this manual. When selecting equipment, the diver should not overburden himself with accessories. Use only the equipment required for safety and completion of the mission or task. When the diver is encumbered with excess equipment, the possibility of entanglement and fatigue increases.

4.2.6 Fulfillment of Safety Precautions

All personnel associated with the diving operation are responsible for maintaining proper safety standards. Ultimately, the diving supervisor (or team leader) must assume responsibility for the safety of the divers. He must evaluate each and every aspect of the operation. Safety is considered in all aspects of preliminary planning. Divers must not be committed to a mission or task which is *unreasonably* hazardous or for which they are not sufficiently trained or equipped. In evaluating environmental conditions and the dive site, the diving supervisor must train himself to anticipate potential hazards and take appropriate measures to protect the divers from these conditions. Naturally, all hazards cannot be eliminated from any diving operation; however, they can be minimized. If a particular hazard is foreseeable, it can usually be eliminated. The diving supervisor may wish to prepare a list of potential hazards, including precautionary measures to use when setting up the operation and briefing the personnel.

4.2.7 Establish Procedures and Brief Personnel

The diving supervisor or team leader, after careful evaluation of the above factors, will establish the operational procedure and brief all personnel. The procedure and briefing should include

- objectives and scope of the operation;
- conditions in the diving area;
- dive plans and schedules;
- assignment of personnel: buddy teams, divers,
- tenders, and specific tasks for each;
- safety precautions; and
- special considerations.

4.2.8 Diving Vessel

Research divers will be required to dive from vessels (or boats) of various sizes and descriptions, ranging from small, inflatable, rubber boats such as the Zodiac to large research vessels 300-400 ft in length. The type and magnitude of diving, operation, and environmental conditions will determine the type of vessel.

For example, nearshore, self-contained diving in relatively calm water may be accomplished without much difficulty from a good quality, rubber, inflatable boat or small, wood, metal, or fiberglass boat equipped with a dependable outboard engine. More extensive offshore, self-contained diving operations or surface-supplied diving must be undertaken from a large vessel with adequate deck space and seaworthiness. The following factors must be considered relative to the mission requirements:

1. Adequate size to comfortably accommodate divers, surface personnel, and equipment.
2. Sufficient stability and seaworthiness to function as a platform for diving operations.
3. Vessel well maintained, in satisfactory operating condition, and equipped with proper safety equipment as required by state and/or federal laws.
4. Large, open, work area.
5. Adequate protection from sun or cold.
6. Mooring capability (3- or 4-point moorings may be required).
7. Sufficient storage space to accommodate diving equipment when not in use.
8. An adequate ladder to facilitate entering and leaving the water.

The diving ladder is a very important part of the boat's equipment. Most boats, unless specifically designed and equipped for diving, will not have a ladder that is safe for use by divers. Serious injuries have resulted from the use of inadequate ladders. The ladder should include the following features:

- metal construction,
- extension 4-5 ft below the water line,
- rungs wide enough to allow comfortable use with bare feet and stability with heavy diver's shoes,
- hand rail extending the full length of the ladder to give the diver a "hand hold" until he is completely on deck,

- inclination of about 10-15 degrees relative to the side of the vessel,
- secure enough to avoid movement when the diver is on it.

4.3 Decompression Procedures

The necessity for decompression depends upon the depth and duration of the dive. Dives should be planned to avoid decompression when possible, especially by self-contained divers. When decompression is unavoidable, the diving supervisor or team leader must provide adequate arrangements for handling it. The standard method of decompression is to bring the diver to the surface with stops at various depths for times as specified by US Navy (1970) standard air decompression tables (Appendix C). In addition, decompression meters are currently widely used for SCUBA diving decompression.

Decompression for self-contained divers is somewhat more complicated than for surface-supplied divers. The dive must be thoroughly planned in advance. Depth, dive duration, and air supply must be properly calculated to insure that the diver is not forced to the surface without adequate decompression. The diver must be equipped with a watch and depth indicator and carry a small slate on which is recorded the decompression schedule.

There are four techniques for decompression in self-contained diving:

1. Plan the dive so that decompression may be completed on the original SCUBA.
2. Switch to a surface-supplied mask or demand regulator at the first decompression stop.
3. Attach a second SCUBA to a line at the first decompression stop.
4. Provide a surface decompression chamber.

Most depth indicators are inadequate for determining precise decompression stop depths. A line or chain marked at 10-ft intervals and weighted heavily enough to keep it vertical in a current is adequate. The diver should hold the line just below the proper marker in any comfortable position where the lower part of his body is not above the marker.

Decompression is generally simpler and safer for surface-supplied divers. Sufficient air supply for completing decompression is available from the compressor or large air-cylinder units. Since the dive duration is timed accurately by surface personnel and depth is determined by sounding or pneumofathometer, the diving supervisor or tender may accurately determine the decompression schedule. The decompression stop depths are indicated by a marked line, pneumofathometer, or markings on the diver's umbilical hose. Decompression is controlled by the diving supervisor and/or tender. A decompression stage may be used to facilitate decompression. If a stage is not available, the diver may be held securely at a given depth by tension on his umbilical hose or he may hold himself in place on the descent line. For long decompressions without a stage, a boatswain chair or sling may be rigged and secured to the descent line with a prussik knot. Surface decompression procedures may be used if a chamber is available.

4.3.1 Automatic Decompression Meter

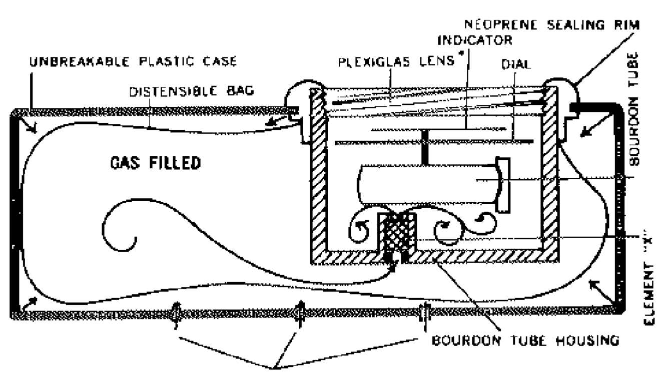
The decompression meter (Figure 4-1) is increasing in popularity among both sport and research divers. In the research diving field, these meters are used by many organizations, including Scripps Institution of Oceanography (personal communication, James Stewart), the University of Washington (personal communication, Charles Birkeland), and The University of Michigan.

The decompression meter is designed to simulate the physiological processes of nitrogen absorption and elimination by the human body. The meter automatically computes the diver's decompression.

In spite of its remarkable function, the meter is uniquely uncomplicated. It is composed of a rigid watertight housing which contains a sealed Bourdon tube, a flow-restricting ceramic filtering element, and a distensible, gas-filled bag, all housed in a stainless steel case. The Bourdon tube is connected to an indicator needle. The distensible, gas-filled bag is attached to the Bourdon tube housing with the filter element located between the two.

The meter starts operating automatically as soon as the diver submerges, allowing water to enter the static pressure ports on the back of the meter. As the diver descends, the pressure compresses the gas in the distensible bag, establishing a pressure gradient between the gas bag and the rigid chamber. The contained gas is

a



b

Figure 4-1. Automatic Decompression Meter (Computer): (a) Illustration Courtesty of SCUBAPRO; (b) Diagram from Anderson (1967).

forced through the element into the Bourdon tube chamber. This filtering or flow-restricting element is a porous ceramic material that has the relatively same diffusion ratio as the mid-level tissue in the human body. The quantity of gas passing through the element is relative to the time/depth factor. The resulting pressure upon the Bourdon tube activates the indicator.

During ascent, a reverse transference takes place with gas diffusing through the element from the Bourdon tube chamber to the distensible bag. This simulates the rate of nitrogen diffusing from the human body. The diver ascends directly to the depth indicated on the meter dial. At this depth he slows his ascent to correspond with the counter-clockwise movement of the indicator around the dial. (In the red sector of the dial, insert dashes represent 10 ft, 20 ft, etc, while the dots represent 15 ft, 25 ft, etc.). Never ascend to a depth shallower than that indicated on the meter. The meter must be used in conjunction with an accurate depth gauge or a marked shot line. It is not necessary to decompress by 10-ft increments. Actually, decompression is more effective if the diver "follows" the indicator up, rather than decompressing by stages, because he maintains a maximum safe pressure differential which allows the greatest exchange of gas from the body. However, at the 10-ft level, it is advisable to wait until the indicator says to surface because it is often impractical to attempt decompression in less than 10 ft of water.

Most SCUBA divers find that the decompression meter is most beneficial for *avoiding* decompression. The diver simply terminates his dive before the indicator enters the decompression zone and surfaces directly at 60 ft/min. The "no-decompression" limits designated by the meter are dependent on cumulative underwater time in a 6-hr period. The zones are designated as follows:

1 hr-2 hr: Cumulative underwater time of 1-2 hr; the "no-decompression" limit is the edge of the first red rectangle indicated by the arrow.

30 min-1 hr: Cumulative underwater time of 30 min-1 hr; the "no-decompression" limit is the round dot.

0-30 min: Underwater time is less than 30 min; the "no-decompression" limit is the radial line adjacent to the numeral 10.

When the diver surfaces, the indicator will be in the memory zone and it will take at least 6 hr for the meter to clear itself. Obviously, another diver cannot use the meter for at least 6 hr. However, the *same* diver may make repetitive dives within the 6-hr period and the saturation (residual nitrogen) time shown on the memory zone from the previous dives will automatically be added to the time of the next dive. This makes the meter a valuable unit for operations requiring a large number of repetitive dives.

The indicator needle normally remains in the small blue zone of the dial. It may wander within this zone in accordance with changes in barometric pressure. However, if the needle is not in the blue zone prior to the initial dive or does not return to this zone 6 hr after termination of diving, it is likely that the meter has been damaged or is faulty. Do not use the meter until it has been inspected, repaired, and recalibrated at an authorized repair facility.

How good is the automatic decompression meter? If used with good judgment, the meter is a valuable accessory for SCUBA divers. Perhaps the best use of the meter is to avoid the necessity of making decompression stops, i.e., when the meter shows that the diver is approaching the "no-decompression" limit, he can surface. The meter is particularly helpful to SCUBA divers who make many repetitive dives to different depths for variable times at depth. Sometimes it is extremely complicated to maintain proper diving schedules using conventional repetitive dive tables for such dives.

A comprehensive comparison of the SCUBAPRO decompression meter and US Navy standard air decompression tables was made by Mount (1970) and other investigators. Using the US Navy tables as a "reference standard," the meter is more conservative at depths less than 80 ft, whereas the tables are more conservative in excess of 80 ft. In other words, the decompression meter indicates decompression required at less bottom time on shallow dives and the tables require decompression before the meter indicates on deeper dives. On decompression dives the meter tends to give more decompression on longer duration dives. In general the meter gives satisfactory (by comparison) multiple dive schedules. Based on Mount's study, however, it appears that repetitive dives with a surface interval of over 6 hr and less than 12 hr on the meter are unsafe and should be avoided. Furthermore, since the meter apparently reaches saturation with a bottom time of 2 hr, it is recommended that it not be used for divers with bottom times (single dive or cumulative) exceeding 2 hr.

The meter is not recommended for short-duration (bottom time of 5 min or less) deep dives. Mount's findings indicate that the meter requires longer total decompression time for longer bottom dives at depths up to 300 ft than equivalent dives in accordance with the tables. For dives to 200 ft or below, the depth of the first decompression stop appears to be shallower by the meter than by the tables. Basically, controlled research data is insufficient and inconclusive to determine the reliability of the meter over depths of 100 ft (Tom Mount, personal communication, 1971) at this time. However, many dives have been completed to depths in excess of 200 ft using the meter and with no apparent complications. Repetitive dives, with the shallower dive first, should be avoided since comparisons with accepted tables schedules are inadequate.

Although these meters appear to be satisfactory for normal operations, they do not take into account the diver's physical condition, amount of work, and other factors affecting the individual's absorption and elimination of nitrogen. Like decompression tables, the meter cannot be considered as "complete" protection against the bends. The diver should still keep track of depth/time factors, as well as surface intervals and other data needed to "double" check against the mechanical factor. The experienced diver can generally judge these factors relative to a meter that is malfunctioning. Periodic checks against another meter is one of the best safety checks. Periodic repair and recalibration service are available for a nominal fee from the manufacturer and US distributor (SCUBAPRO). A factory check and recalibration are highly recommended at periodic intervals, depending on the amount of use and abuse. Some divers carry two meters as a check for accuracy; however, most divers cannot afford this luxury.

Although the meter is used on thousands of dives each year without occurrence of bends, it is not infallible. The meter must be used with common sense and good judgment. Do not interpolate or "push" the meter or exceed the apparent limitations as previously stated. The meter is extremely susceptible to shock and damage from excessive abuse. If a meter is dropped or otherwise damaged, it should be returned to the factory for repair and recalibration. Also, when being transported by air, the meter must be shipped within the pressurized portion of the aircraft or in a pressure-proof container. Most divers carry their meters with them in the airplane cabin.

The meter should be rinsed in fresh water, dried, and properly stowed after each use. Do not attempt to disassemble the instrument or clean the static pressure ports under any circumstances. This could result in severe damage and subsequent malfunction.

The manufacturer recommends periodic testing of the meter. This test is conducted as follows:

- Subject the meter to a pressure equivalent to exactly 30 m sea water (98.425 ft) in a chamber or by immersion in water.
- Maintain the meter at this depth for exactly 30 min.
- Rapidly return the meter to the surface and check to see if the pointer is in the zone of the second red rectangle (± 1 mm displacement allowable).

If the needle doesn't fall within the stated range, the meter is malfunctioning and must be returned to an authorized inspection and repair facility.

4.3.2 Repetitive Dives

A dive performed within *12 hr* of surfacing from a previous dive is a repetitive dive. The period between dives is the surface interval. In conventional diving, for all practical purposes, excess nitrogen requires approximately 12 hr to be effectively eliminated from the body. The minimum surface interval requiring repetitive dive computation using the US Navy procedures is 10 min. For any interval under 10 min, add the bottom time of the previous dives to that of the repetitive dive and choose the decompression schedule for the total bottom time and the deepest dive. Specific instructions are given with the US Navy standard air decompression and repetitive dive tables in Appendix C.

All divers, both sport and research, must understand and be able to calculate dive schedules using the repetitive dive tables. This is the standard method of determining decompression schedules and of avoiding decompression when planning multiple dives. Regardless of the current upward trend in the use of the decompression meter for repetitive dives, the tables are still the only method for the majority of divers who do not have access to decompression meters. Repetitive dive work sheets are included in Figures 4-2 and 4-3.

4.3.3 Interrupted or Omitted Decompression

A diver may be forced to surface prior to completing required decompression, especially when using SCUBA. In this event he must

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

___minutes } see table 1-10 or 1-11 for
____feet } repetitive group designation } Group___

II. SURFACE INTERVAL:

__hours___minutes on surface } see table 1-12
Group___(from I.) } for new group } Group___

III. RESIDUAL NITROGEN TIME:

____feet (depth of repetitive dive) } see table
Group___(from II.) } 1-13 } ___minutes

IV. EQUIVALENT SINGLE DIVE TIME:

___minutes (residual nitrogen time from III.)

(add) ___minutes (actual bottom time of repetitive dive)

(sum) ___minutes

V. DECOMPRESSION FOR REPETITIVE DIVE:

___minutes (equivalent single dive time from IV.) } see table
____feet (depth of repetitive dive) } 1-10 or 1-11

☐ No decompression required

or

Decompression stops: ____feet____minutes
____feet____minutes
____feet____minutes
____feet____minutes

Figure 4-2. Repetitive Dive Worksheet (US Navy, 1970)

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

24 minutes, 105 feet — see table 1-10 or 1-11 for repetitive group designation — Group H

II. SURFACE INTERVAL:

2 hours 0 minutes on surface, Group H (from I.) — see table 1-12 for new group — Group E

III. RESIDUAL NITROGEN TIME:

145 feet (depth of repetitive dive), Group E (from II.) — see table 1-13 — 12 minutes

IV. EQUIVALENT SINGLE DIVE TIME:

12 minutes (residual nitrogen time from III.)

(add) 15 minutes (actual bottom time of repetitive dive)

(sum) 27 minutes

V. DECOMPRESSION FOR REPETITIVE DIVE:

27 minutes (equivalent single dive time from IV.), 145 feet (depth of repetitive dive) — see table 1-10 or 1-11

☐ No decompression required

or

Decompression stops: 20 feet 8 minutes
10 feet 24 minutes
____ feet ____ minutes
____ feet ____ minutes

Figure 4-3. Repetitive Dive Worksheet with Example of Computation for a Repetitive Dive (US Navy, 1970) enter a decompression chamber or return to the water to complete his decompression. If a chamber is available, immediately recompress the diver to 100 ft for 30 min and bring him up in accordance with Treatment Table 1 or 1A (US Navy, 1970). If a chamber is not available, the diver should be returned to the water and decompressed using the following procedure, based on the standard air decompression tables (US Navy, 1970):

- At 40 ft, remain for one-fourth of the 10-ft stop time.
- At 30 ft, remain for one-third of the 10-ft stop time.
- At 20 ft, remain for one-half of the 10-ft stop time.
- At 10 ft, remain for one and one-half times the scheduled 10-ft stop time.

Upon completing this procedure, the diver should be observed for symptoms of decompression sickness, and stand-by arrangements for transport to a chamber should be in effect. The US Navy (1970) suggests that Treatment Table 1 or 1A procedures may be attempted at sea; however, it is unlikely that this procedure would be successful for nonmilitary or noncommercial diving operations since it requires surface-supplied equipment, proper water depth, sufficient air supply, sufficient thermal protection, etc. Inadequate decompression on Treatment Table 1 could seriously injure the diver and possibly be worse than the delay required to transport a diver to a chamber if he should exhibit symptoms of decompression sickness.

4.3.4 Decompression for Dives at High Altitude

Standard US Navy air decompression tables are computed for diving with reference to sea level. Two modifications must be made to correct for differences in atmospheric pressure when these tables are used at high altitude. The diver must compute, or refer to a table to obtain, the theoretical depth of the dive and the theoretical depth of decompression stops for a given altitude. Both the theoretical diving depth and decompression stop depths will vary with altitude. There are various procedures and tables for computing decompression for high-altitude diving. The tables are based on theoretical calculations, and most have not been thoroughly tested. The following procedures and tables given are those recommended by Cross (1967, 1970). These procedures and tables are given because of prior wide distribution and apparent acceptance by divers. I do not accept responsibility for the accuracy or reliability of these procedures and tables.

Theoretical diving depths to 10,000 ft for actual diving depths to 250 ft are given in Table 4-1. To find the theoretical diving depth, enter the table at the exact or the next greater depth than the maximum actual depth attained during the dive. Enter the table horizontally with this depth to the vertical column of the exact or next greater altitude (listed at the top of the column) of the body of water in which the dive is being made. The figure given in the selected altitude column for the actual depth is the theoretical depth of the dive at that altitude. Once the theoretical dive depth has been found, standard US Navy air decompression tables (US Navy, 1970) are used to determine decompression time. Decompression stop depths are computed using Table 4-2 in a similar fashion.

For example, assume that a dive is to be made in a lake at an altitude of 3860 ft and the actual depth of the dive is 85 ft. By entering Table 4-1 to 90 ft and across to 4000 ft altitude, it is found that the theoretical dive depth is 104 ft. This means that an 85-ft dive at 4000 ft is equivalent to a 104-ft dive at sea level. Since the rule of using the exact or next greater depth applies, the theoretical depth used in determining decompression for this dive would be 110 ft.

Further assume that the above dive is for a bottom time of 36 min. Entering standard air decompression tables for a depth of 110 ft and duration of 40 min (next greater time from 36 min), it will be found that the decompression schedule requires a stop at 20 ft for 2 min and 10 ft for 21 min. The prescribed decompression stop depths must be converted to theoretical decompression stop depths for an altitude of 4000 ft using Table 4-2. Consequently, the diver actually makes decompression stops at 17 ft (instead of 20 ft) and 9 ft (instead of 10 ft).

Repetitive dives may be computed using theoretical depth values. Use the repetitive group designator given for the theoretical dive depth at a given altitude. In the surface interval credit table, no modifications are required since depth is not a function of this table. However, theoretical depth must be used when determining residual nitrogen time using the repetitive dive time table. For example, assume that a "no-decompression" repetitive dive is to be made to an actual depth of 60 ft after a surface interval of 2 hr. The initial dive, to a theoretical depth of 104 ft for a bottom time of 36 min, indicates a repetitive group "L." Following the 2-hr surface interval, the repetitive group designation is "G." The sea-level equivalent of a 60-ft dive at 4000 ft altitude is 69 ft (Table 4-1). Consequently, the residual nitrogen time, entering the repetitive dive time table

Actual Depth	Theoretical Depth at Various Altitudes (in feet)									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
0	0	0	0	0	0	0	0	0	0	0
10	10	11	11	12	12	12	13	13	14	15
20	21	21	22	23	24	25	26	27	28	29
30	31	32	33	35	36	37	39	40	42	44
40	41	43	45	46	48	50	52	54	56	58
50	52	54	56	58	60	62	65	67	70	73
60	62	64	67	69	72	75	78	81	84	87
70	72	75	78	81	84	87	91	94	98	102
80	83	86	89	92	96	100	103	108	112	116
90	93	97	100	104	108	112	116	121	126	131
100	103	107	111	116	120	124	129	134	140	145
110	114	118	122	127	132	137	142	148	153	160
120	124	129	134	139	144	149	155	161	167	174
130	135	140	145	150	156	162	168	175	181	189
140	145	150	156	162	168	174	181	188	195	203
150	155	161	167	173	180	187	194	202	209	218
160	166	172	178	185	192	199	207	215	223	232
170	176	182	189	196	204	212	220	228	237	247
180	186	193	200	208	216	224	233	242	251	261
190	197	204	212	220	228	237	246	255	265	276
200	207	215	223	231	240	249	259	269	279	290
210	217	225	234	243	252	261	272	282	293	305
220	228	236	245	254	264	274	284	296	307	319
230	238	247	256	266	276	286	297	309	321	334
240	248	258	267	277	288	299	310	323	335	348
250	259	268	278	289	300	311	323	336	349	363

Table 4-1. Theoretical Depth at Altitude for Given Actual Diving Depth

Prescribed	Theoretical Depth of Decompression Stop (in feet)									
Depth	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
0	0	0	0	0	0	0	0	0	0	0
10	10	9	9	9	8	8	8	7	7	7
20	19	19	18	17	17	16	15	15	14	14
30	29	28	27	26	25	24	23	22	22	21
40	39	37	36	35	33	32	31	30	29	28

Table 4-2. Theoretical Depth of Decompression Stop at Altitude (Cross, 1970)

at repetitive group "G" to a depth of 70 ft, is 37 min. Since the "no-decompression" limit is 50 min, this means that the repetitive dive cannot exceed 13 min actual bottom time.

If for any reason an initial dive is made at altitude and a repetitive dive at a lower altitude or sea level, simply assume that the initial dive was made at the lower altitude. Consult tables for the lower altitude (in the case of an ocean repetitive dive, the actual depth). However, if the initial dive is made at sea level or a lower altitude and the repetitive dive at high altitude, the initial dive must be treated as if it were made at the *higher* altitude. The repetitive dive would be computed for the higher altitude as previously discussed. For further information on diving at high altitude, consult Cross (1967, 1970).

4.3.5 Surface Decompression

The primary advantages of surface decompression in a chamber are the comfort and security provided to the diver by allowing him to surface in case of extremely cold or rough seas, physical exhaustion, equipment malfunction, etc. If the chamber is equipped with a proper oxygen breathing system, the use of pure oxygen saves an appreciable amount of the total decompression time required as compared to air decompression. In surface decompression procedures, stage decompression in the water is reduced to a minimum or is eliminated and the major portion of the decompression is accomplished in a surface chamber in accordance with US Navy Surface Decompression Tables 1-26 and 1-27 (Appendix C). If decompression is to be on oxygen, use Table 1-26 with an initial ascent rate of 25 ft/min instead of the standard rate of ascent for air diving. For surface decompression on air, use Table 1-27 with an ascent rate of 60 ft/min. Following completion of required water stops, ascend directly to the surface, enter chamber, and pressure down as soon as possible. Do not exceed 3.5-min surface interval. Consult US Navy (1970) for details of surface decompression procedures and chamber operation.

4.3.6 Diver's Log Book

The diver's log book is a permanent record of his training, experience, and qualifications. A record of diving experience is necessary for advancement in research diver classification and instructor certification. Divers are encouraged to keep accurate records of all diving activities.

The following information should be recorded for all dives:

1. date,
2. geographic location,
3. underwater time,
4. depth,
5. equipment used,
6. swimmer or tender,
7. purpose of the dive and a brief description of work accomplished.

In addition, the following information is desirable:

1. diving conditions (underwater and surface),
2. air source and consumption,
3. exertion level,
4. comments on equipment and diver performance,
5. cumulative record of dives and underwater time.

Several commercially prepared log books are available; however, these are generally inadequate for research diver's records. A permanently bound notebook (approximately 4 in. by 6 in. or 5 in. by 8 in.) has proven satisfactory. Specially printed log sheets carried in a loose-leaf binder are used in The University of Michigan's program. It is recommended that a "rough log" be prepared in the field during operations and information be entered in the permanent log book at the end of each diving day.

4.4 Diving In Cold Water

A survey of civilian diving activities in the United States indicates that 83 percent of all divers are in water below 60° F, 60 percent of all divers are in water between 60° F and 40° F, and 25 percent of all divers are in water below 40° F (Frey, 1967). Of these dives, 44 percent have a duration of 90 min or longer and 33 percent have a duration of 45-90 min. In diving, the major cause of physiological depletion is cold stress. Cold is a major limiting factor relative to diver performance, comfort, and safety.

Initially, upon submergence in cold water there is a mobilization of the body's heat generation and insulation resources to resist the cold. This response is characterized by immediate cooling of the body's surface layers, vascoconstriction, metabolic rate increase with possible increase in core temperature, respiration increase, and a decrease in heart rate. Continued exposure results in localized cooling, with the hands and feet exhibiting the most rapid rate of heat loss.

The hands and feet cool rapidly because they have the greatest skin surface area to mass ratio of all body regions and little or no subcutaneous fat. The diver's finger dexterity, tactile discrimination, and kinesthetic sensation diminish, with subsequent reduction in his ability to perform manual skill tasks. Loss of manual skill, even by degrees, results in a deteriorated state of efficiency and safety. The diver's ability to make critical value adjustments and handle emergency situations is impaired. The diver is, however, still capable of performing certain tasks. For example, a diver may adapt by using the side of his hand to thread a nut onto a bolt instead of his impaired fingers. Also, individual variations in susceptibility to cold and discomfort, skill level, and motivation play a major role in diver performance under cold stress.

Cooling of the hands and arms results in a marked decrease in muscle strength. A 50 percent reduction in grip strength can be expected when an unprotected subject is immersed in 50° F water for 1 hr. The diver's ability to board a boat or ascend a diving ladder without assistance may be impaired. Tenders and surface personnel must be prepared to render assistance.

Cold stress causes deterioration in motor and mental processes. Visual perception, sensory motor coordination, and anticipation (purely a mental process) are affected to various degrees. The loss of mental agility (problem-solving ability) and memory impairment are symptomatic of severe cold stress. Cold stress may limit the amount of information that one can retain and can also be responsible for erroneous recollection, both vital factors in scientific observations. At this point man is not only useless as a working diver, but he is a hazard to himself and his colleagues.

Further exposure can lower core temperature (normal: 98.6° F ± 1°) and skin temperature (normal comfort: 91.5° F to 87.8° F). When core temperature drops to 97° F, the central nervous system's neuroregulatory capacity is affected, and severe pain followed by nerve damage is indicated when skin temperature drops below 55° F.

4.4.1 Wet Suit

The foamed-neoprene, wet-type diving suit (Figure 4-4) is probably the most widely used suit today. With a properly fitted suit, only a small quantity of water is able to enter and this water is quickly warmed by the body. Heat loss is restricted by the insulating properties of the closed-cell, foamed-neoprene material. Unfortunately, this material is subject to compression under pressure

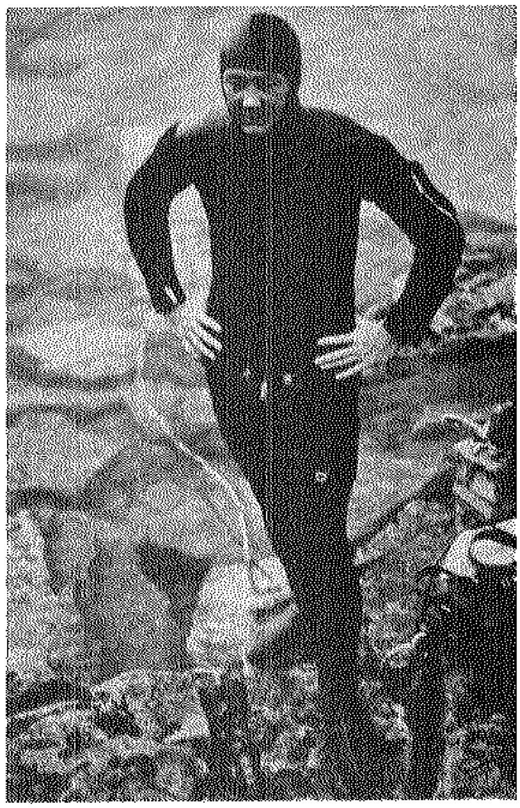


Figure 4-4. Protective Suit for Divers--Foamed-Neoprene, Wet-Type Diving Suit for Cold-Water Diving (Photo by P. Blackburn)

and its insulating effectiveness decreases with depth. In contrast, an incompressible wet-suit material constructed of rubber impregnated with tiny gas-filled spheres is currently undergoing development and testing. This material shows promise as an ideal material for insulating the diver; however, at present it is rather bulky and heavy. An incompressible wet suit was marketed later in 1971.

Insulation is primarily dependent on foamed neoprene thickness. Wet suits are commonly available in 1/8-in., 3/16-in., 1/4-in., and 3/8-in. thickness. Selection of suit thickness depends on water temperature, mission requirements (continuous swimming or limited underwater activity), dive duration, and individual comfort preference (thicker suits are more restrictive). The following are suit thickness recommendations for various temperature ranges:

- 70° F and above — 1/8-in. jacket,
- 60° F to 70° F — 3/16-in. suit (standard),
- 50° F to 60° F — 1/4-in. suit (standard).

The *standard wet suit* consists of a jacket with zippers in the front and arms, pants with leg zippers, a hood, boots, and glove-mitts (3-finger type). Various design modifications and accessories are used to increase thermal comfort and protection. *Suspender-type pants* ("bib" type or "Farmer John" type) which resemble sleeveless coveralls are commonly used to provide added thermal protection to the diver's torso, the area of greatest heat loss. The 1/8-in. or 3/16-in. *hooded vest* is highly recommended for increasing thermal protection and allowing for seasonal variation. This vest prevents significant water seepage to the chest area (through zipper) and the back of the neck. It is extremely important to protect the head and back of the neck from cold-water exposure since these areas are highly sensitive to cold and have significant effects on the body's thermal balance. Added torso protection is afforded by a 3/8-in. shirt body. One-fourth-inch sleeves and hood may be used on the 3/8-in. body to provide for minimum arm movement restriction and head comfort. For extremely cold water (28° F to 35° F), a 3/8-in. suit or *multisuit* arrangement is desirable. Some divers prefer a 1/8-in. or 3/16-in. suit over or under a 1/4-in. suit.

Standard suits are equipped with leg, arm, and chest zippers backed with a neoprene overlap strip to minimize water seepage. Zippers facilitate easy and rapid dressing and undressing. Unfortunately, they also constitute a weakness in the insulation barrier and allow cold-water seepage. Zippers are frequently eliminated from suits designed for extremely cold-water diving or are backed with special backing pieces (gussets) glued and sewn to both sides of the zipper opening. If zippers are used, heavy-duty nickel-silver models are currently recommended.

Hands and feet exhibit the most rapid cooling rates. In moderate temperature waters and when finger dexterity is required for manual skill performance, divers frequently wear 1/8-in. or 3/16-in., five-finger, foamed-neoprene gloves. Unfortunately, gloves offer only minimal thermal protection. The three-finger glove mitt (3/16 in. or 1/4 in.) is most commonly used in cold water. For extremely cold water, a *gauntlet type*, 1/4-in. mitt designed to reach to just below the elbow is recommended. Gloves and mitts must be carefully fitted since the slightest restriction in the fingers will impair circulation and cause cold and numb fingers.

Footwear must be properly fitted to keep the diver's feet warm, yet prevent cramping and circulation restrictions. Foamed-neoprene *boots* with a hard rubber or felt sole are designed to minimize wear (damage to bottom surface) and to protect the diver's feet when walking. Since the bottom is generally constructed of hard rubber with low insulating properties, a neoprene insole is recommended. Recently some manufacturers have improved protection by simply securing a hard sole to the bottom of a specially designed neoprene sock. The neoprene *sock*, without a hard sole, is designed to fit the foot snugly like a regular sock. Some sort of overboot or shoe is required to protect the foot and soft neoprene when walking on rough surfaces. High-top boots reaching to just below the knee are recommended for extremely cold water.

Hoods must be designed to give maximum protection to the head, neck, and face; however, they should not interfere with proper fitting of the mask and SCUBA mouthpiece. Proper sizing can be extremely important because the skull is rigid and requires more accurate fitting than other suit parts. A poorly fitted hood can cause severe jaw fatigue, a choking sensation, a headache, dizziness, and coldness. An extremely tight-fitting hood and suit neck could cause unconsciousness by restricting blood flow to the head. This condition is known as carotid sinus reflex (Shane, 1971). Pressure on the carotid arteries in the neck region can stimulate the heart to reduce blood flow to the cerebral area. Consequently, symptoms similar to those of hypoxia will be evident and eventually the diver will loose consciousness. For extremely cold water, Neushul (1961) states that no part of the face should be in direct contact with the water if diving is to be continued for extreme periods. This requires a special hood design with separate openings for the mouthpiece and mask. Ray and Lavallee (1964) concluded that this is not necessary. I have noted facial discomfort and numbing of the facial area and lips with possible impairment of one's ability to retain a SCUBA mouthpiece. A full face mask over a standard hood has merits. A special cold-water hood which extends well over the shoulder area is available. However, I suggest that the outer shirt should have an attached hood for cold-water diving. This may be worn over a hooded vest, a high-neck vest with separate 1/8-in. hood, or a vest without a hood.

Most wet suits are currently lined with four-way stretch nylon fabric. This *nylon lining* facilitates dressing and retards tearing. There is a slight reduction in suit flexibility, and some divers claim that thermal protection is reduced. No scientific data is available to support this reduction in thermal protection factor. The nylon lining also serves as a base for sewn seams. The *sewn seam* is desirable since it virtually eliminates tearing at seams. The advantages of nylon linings appear to outweigh the disadvantages; consequently, nylon lining is recommended.

The outer surface of the suit may be smooth or textured rubber or nylon covered. Some manufacturers claim that the textured surface increases flexibility and is more resistant to abrasion. Most suits are currently manufactured with textured surfaces, although distinct advantages of textured surfaces relative to smooth surfaces are not clearly defined. A *nylon outer surface* significantly increases suit durability. A slight decrease in flexibility is evident; however, the nylon surface is desirable for the working diver.

Other factors to consider when selecting a wet suit include color, crotch strap snaps, and spine pad. Black rubber is preferable since coloring compounds may tend to weaken material and lower elasticity. Twist-lock fasteners are commonly used to secure the crotch. Some manufacturers are now successfully using a specially designed velcro fastener for crotch straps. The shoulder straps of suspender-type pants should be secured with large velcro strips. Spine pads are used to reduce the flow of water in the spinal area.

Although production-model wet suits are available in a wide range of sizes, including longs, regulars, and shorts, custom-tailored suits are recommended. A custom suit is tailored to 20 or 30 personal measurements, and various modifications may be specified by the diver. Fit is extremely important. A wet suit should fit snugly; not too tight to restrict circulation, yet not too loose to allow excess seepage and accumulation of water. Too tight of a fit in the chest area can result in restriction to breathing with subsequent respiratory fatigue. A good-quality suit will fit snug and comfortably, but will stretch with body movement.

Most divers will not be fortunate enough to have two or more wet suits to use for various water temperature ranges. Taking into consideration comfort, thermal protection, versatility, and cost, the following suit and accessories are recommended for the 40° F to 70° F temperature range:

Shirt: 1/4 in.; no zippers in arms,

Pants: 1/4 in.; no zippers,

Vest: 1/8 in.; hooded,

Boots: 1/4 in.; hard sole,

Mitts: 1/4 in.; glove-mitts,

Hood: 3/16 or 1/4 in.

Cold-water wet suits are discussed by Ray and Lavallee (1964) and Neushul (1961). Current investigations, in general, support the conclusions of these authors with regard to wet-suit design. The following wet suit (custom tailored) has been proven satisfactory for water temperatures of 40° F to 50° F (moderate activity level):

Shirt: 3/8-in. body with 1/4-in. sleeves and attached hood (sleeve zippers with gussets and inverted shirt zipper are optional);

Pants: 1/4 in., suspender type, cut high in neck;

Vest: 1/8 in., hooded or turtle-neck, neoprene;

Boots: 1/4 in., hard sole;

Mitts: 3-finger glove-mitts.

For arctic diving conditions and in water temperatures of 28° F to 40° F, the following wet suit (custom tailored) is recommended:

Shirt: 3/8 in. with attached hood, no zippers;

Pants: 3/8 in., suspender type;

Vest: 1/8 in., hooded;

Boots: 3/8-in. foot with 1/4-in. upper to just below knee;

Mitts: 1/4 in. or 3/8 in., gauntlet type extending to just below elbow.

4.4.2 Dry-Wet Suit

Recently, a foamed-neoprene, wet-type suit has been developed that is virtually watertight. Entry is gained through a waterproof, pressureproof rear zipper, and the cuff, leg, and neck seals are specially constructed to minimize water entry. This unit appears to be advantageous in keeping the diver relatively dry and requires less critical fit. However, the same compression is noted with depth as in a standard wet suit, and similar insulation reduction is evident.

4.4.3 Wet-Suit Buoyancy

The amount of weight required to offset the buoyancy of a foamed-neoprene wet suit is primarily determined by the depth of the dive. The small, closed, gas cells in foamed-neoprene rubber are compressed as pressure is increased and, thus, the flotation, or buoyancy, factor is decreased. Several methods may be used to determine the amount of weight necessary to achieve neutral buoyancy. To determine surface buoyancy, the diver must don all of the equipment which he plans to wear during the dive. Wearing a weight belt with clip-on lead weights or carrying weights in a net bag, he enters the water and adds or subtracts weight until he achieves a state of neutral buoyancy. At neutral buoyancy, he should sink slightly with exhalation and rise with inhalation. This amount of weight is generally satisfactory for diving in depths of less than 30 ft. Remember that a full, standard, 71.2 ft^3 SCUBA cylinder contains approximately 5 lb of air; consequently, the diver can expect to be about 5 lb more buoyant at the end of a dive when his air has been depleted. Minor buoyancy compensations may be made using the diver's lifejacket. This technique is discussed in the section on SCUBA diving equipment.

The diver may theoretically determine his weight requirements at depth by using a buoyancy-depth graph for foamed-neoprene wet suits (Figure 4-5). For example, a diver wearing a medium-size, 1/4-in., wet suit will find that the suit has approximately 18 lb of buoyancy at the surface and 8 lb of buoyancy at a depth of 100 ft. Consequently, he will need to remove 10 lb of weight from his belt to maintain the same buoyancy at 100 ft as he had at the surface. The graph is only intended to serve as a general guide. Since various factors, including neoprene rubber quality, suit age and condition, individual body types, and equipment affect buoyancy, only personal experience can ultimately determine weight requirements.

The density difference between fresh and salt water has only a slight effect on the suit's buoyancy. Since the graph is for fresh water, the figures may be multiplied by a factor of 1.03 for saltwater diving. Remember, however, that the diver must add weight when he makes the transition from fresh water to salt water to compensate for his body's displacement. For example, if a 180-lb individual dressed in a bathing suit is neutrally buoyant in fresh water without the addition of weight, he will displace approximately 2.88 ft^3 or 180 lb of fresh water. This same individual will displace about 184 lb of salt water. Since he weighs only 180 lb, approximately 4 lb of weight must be added to achieve neutral buoyancy in salt water.

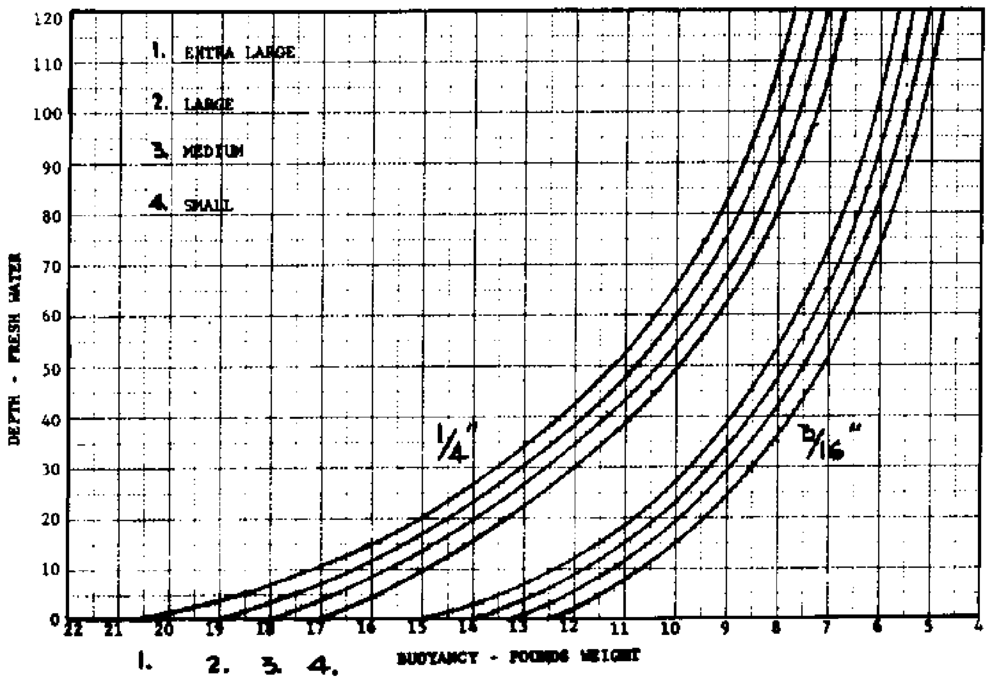


Figure 4-5. Buoyancy of Foamed-Neoprene, Wet-Type Suit Relative to Compression at Various Depths (Dey, 1965)

Frequently, novice divers will find that they will reduce their weight belt requirements by 4 to 5 lb during the first year of diving. Certainly part of this reduction is due to improvement in skill, relaxation, and breathing characteristics. However, about half of this reduction is due to wet-suit deterioration through normal usage.

A rapid alternate, but less accurate, method of determining the amount of weight required by a diver wearing a wet suit to achieve neutral buoyancy at the surface is the formula of 1 lb of lead for each 10 lb of body weight.

4.4.4 Dry Suit: Standard

The standard dry suit (Figure 4-6) is generally made of two-ply gum rubber and is worn over one or more layers of thermal or woolen underwear or a foamed-neoprene wet suit. Dry suits are commonly classified by type of entry: neck, front, rear, or waist. The front- and waist-entry models are currently popular.

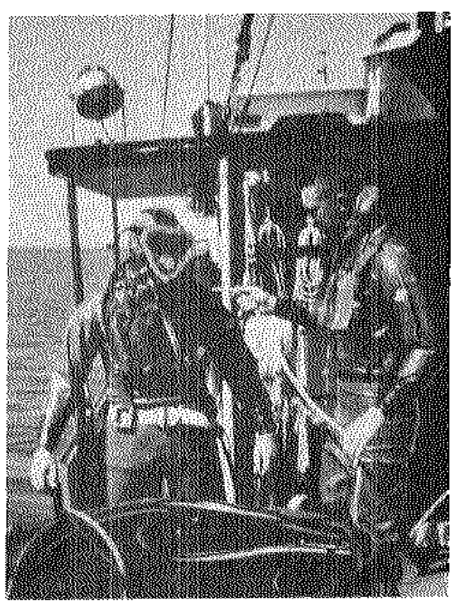


Figure 4-6. Protective Suits for Divers: Standard Dry Suit (Photo by P. Josephson)

Dry suits were used for most cold-water diving prior to introduction of the wet-type, foamed-neoprene suit. Unfortunately, dry suits are subject to leakage if the entry is not properly sealed. Also, a slight tear can result in complete wetting of the undergarments and subsequent loss of thermal insulation properties. The dry suit is frequently uncomfortable at depth due to squeeze as the air in the suit is compressed. Since insulation properties depend on the thickness of the air space provided by the undergarments, thermal protection decreases with depth. Air may be introduced into the suit through the face seal from the mask to partially compensate for compression and prevent external ear squeeze. Some divers wear thick, porous padding in their hoods to help prevent ear squeeze.

The dry/wet suit combination has proven adequate for long-term submergence in shallow cold water where the diver must remain relatively immobile. The wet suit is worn as an undergarment; thermal protection is thus retained in the event of leakage. Unfortunately, this combination is rather restrictive to movement and may induce fatigue during long underwater swims.

After entrance is made into the front or rear entry dry suit, the entrance tunnel must be made watertight. The following method of making a watertight seal is recommended:

1. Spread the entry tunnel flat at the open end.
2. Fold once and carefully pleat the entire length.
3. Hold securely and clamp or tie (elastic cord) the pleated material.

To seal the waist entry dry suit, the following method is recommended:

1. Fold pants entry chute over hip.
2. Lay shirt entry chute over the pants chute and fold so that the shirt entry is now on the inside and the pants chute is on the outside.
3. Place the rubber tube belt at the top of the entry chutes and roll the chutes downward. (The tube belt is optional: proper seal may be made without a belt.)

When wearing a dry suit, do not jump into the water. Enter gradually and purge trapped air out of the cuffs or face hold. If attached gloves are used, submerge one at a time while purging air. Extreme caution must be observed when using a dry suit to prevent external ear squeeze or rupture of the eardrum. This problem is eliminated by admitting air from the mask through the face seal.

Instead of attaching gloves to the suit, most divers now use heavy, foamed-neoprene, wet-type mitts. If dry-type mitts or gloves are desired, the best method of attachment is to simply remove the suit cuffs and cement the gloves in place.

After using the dry suit, it must be thoroughly dried, powdered, and stored in a dry, cool, dark area. Avoid excessive heat. Roberts (1963) discusses the use of dry suits, dry-wet suit combinations, and suit entry techniques in detail.

4.4.5 Dry Suit: Variable Volume

The variable-volume, dry suit (Figure 4-7) is a flexible, lightweight, one-piece, dry-type suit with integral boots and hood, and separate glove-mitts. It is constructed of 3/16- or 1/4-in., closed-cell, neoprene rubber with a nylon-lined interior and

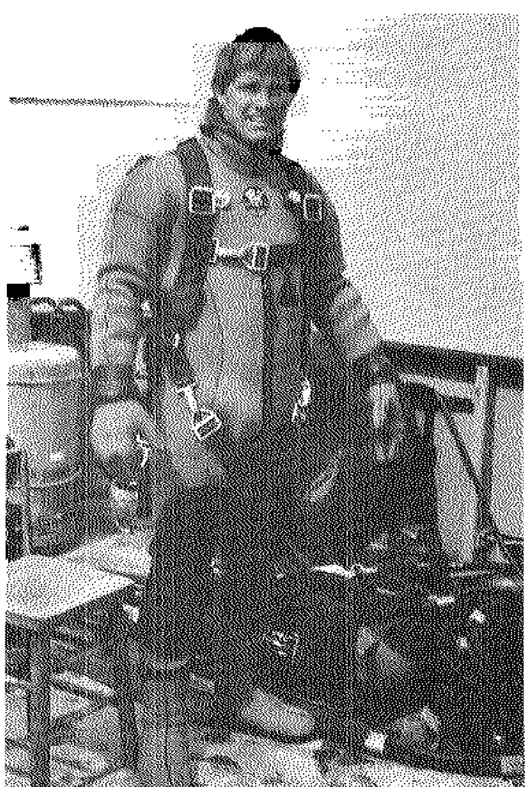


Figure 4-7. Protective Suits for Divers: Variable-Volume Dry-Type Suit (Photo by Somers)

textured-rubber or nylon exterior. The seams are stitched and large kneepads are affixed. The suit is entered through an opening that extends from the breast bone down around the crotch and up to the nape of the neck in back. A waterproof, pressure-proof zipper completely seals the opening and permits the diver to dress and undress in approximately 5 min. The suit is designed to be worn with light or heavy underwear and may be used with SCUBA mask or surface-supplied lightweight helmet.

This suit is fitted with inlet and outlet valves to permit diver control of inflation and deflation of the suit, thus permitting control of displacement and buoyancy. Air supply for the suit is taken from the diver's air supply (SCUBA or umbilical hose) through a hose attached to a low-pressure outlet on the regulator or umbilical hose, or from a small auxiliary cylinder. Controlled inflation produces only limited local ballooning, and squeeze is minimized since the elasticity of the suit material facilitates equalization of pressure differentials over the entire body. While the neoprene rubber is compressed with increasing depth, the insulation properties of the underwear and the air envelope surrounding the diver are relatively unimpaired.

The diver may utilize the variable-volume factor to control buoyancy and thus allow a wide range of weight to be used safely. Approximately 25-30 lb of weight are required to neutralize the buoyancy of the suit. To allow the diver to swim with neutral buoyancy and work heavy, 10-15 lb of weight may be added. For work requiring maximum stability on the bottom and no swimming, up to 40 lb of weight may be added in the form of a heavy weight belt and diver's shoes and/or leg weights.

The suit is also an effective life preserver. Inflation of the suit allows a surfaced SCUBA diver to float on his back above wave action. If the diver were to lose consciousness during ascent, air would automatically vent through the wrist seals. Blowup may be controlled by venting air from the exhaust valve, through wrist seal cuffs, or by unzipping the suit.

Currently, a variable-volume dry suit is manufactured in Sweden and marketed under the name UNISUIT. Using heavy "arctic" underwear (a knitted nylon-fur suit supplied by the manufacturer), the Swedish navy has tested the suit in water temperatures of 37° F to 50° F at depths of 60-100 m. Tests conducted in my presence on a recent arctic expedition included a 2.5-hr dive in shallow (to 30 ft) water with a temperature of 29° F to 30° F. Further testing by myself has indicated satisfactory performance to depths of 200 ft in cold water with lightweight helmet and mask.

Specific instructions for use and maintenance of the UNISUIT are supplied by the manufacturer; divers are encouraged to follow these instructions to avoid malfunction and unnecessary suit damage. The zipper requires special handling and maintenance procedures.

4.4.6 Dry Suit: Constant Volume

The constant-volume dry suit was designed primarily for self-contained or surface-supplied diving in extremely cold or contaminated water. It is constructed of rubberized cotton twill similar to that used in conventional deep-sea or lightweight diving dresses (suits). As the diver descends, the internal volume of air is kept nearly constant by exhalation of air into the suit through the diver's mouth or nose. Constant automatic exhaust valves located at each ankle of the suit and in the top of the hood automatically maintain pressure balance and vent air during ascent to prevent over-inflation of the suit. The hood is fitted with a hinged-lens face mask and a mouthpiece "T" connection for use with a double-hose regulator. Entry is through the neck opening; the hood is sealed to the suit with a special metal ring.

The constant-volume suit is extremely durable. Currently, this suit is used more often with a surface-supplied demand regulator system than SCUBA. The suit is somewhat cumbersome and uncomfortable for long underwater swims.

4.4.7 Diving Suit: Open-Circuit, Hot-Water System

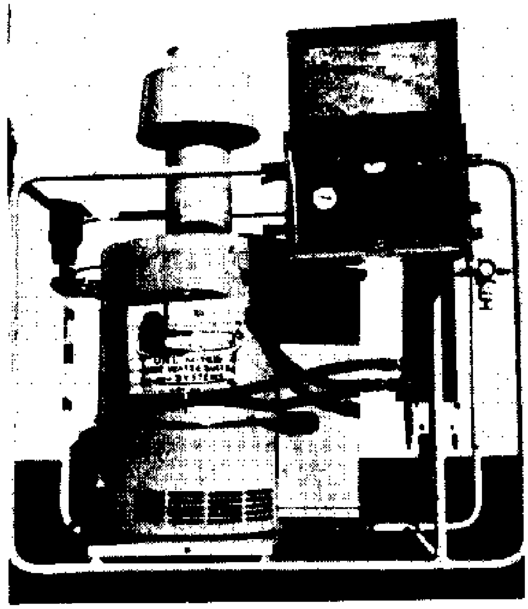
The open-circuit, hot-water system (Figure 4-8) consists of a loosely fitted wet suit designed with internal tubing to distribute heated water uniformly over the diver, an insulated hose, a surface water-heating unit, and a water pump. The one-piece, front-zipper entry suit is constructed of 3/16 in. of foamed neoprene with nylon on both sides. An insulated hose from the heating unit attaches to a control manifold mounted on the side of the suit, enabling the diver to control the flow of water. The size of the surface water-heating unit used depends on depth, number of divers, and water temperature requirements. A satisfactory unit for 1 or 2 divers is a portable, liquid-propane flame to coil 200,000-BTU water heater similar to a small swimming pool heater. The unit is equipped with a mixing manifold to control water flow rate and temperature. A pump is required to pass water from its source through the heat exchanger and down to the diver. A constant flow of 1.5-2 gal/min is required to maintain comfort in cold water. A 40 lb/in^2 head is sufficient for most operations and the water temperature is adjusted to reach the diver at his desired comfort level, generally 90° to 100° F. Since the suit provides little thermal protection in itself, all possible precautions must be taken to avoid loss of hot-water supply. In cold water a diver may suffer symptoms of shock and exposure soon after the flow of hot water ceases.

4.4.8 Diving in Cold Water

Cold-water divers must have adequate predive rest and nutrition. At least 6-8 hr of sleep and caloric intake of at least 5000 cal/day and possibly as much as 7500 cal/day is recommended (Ray and Lavallee, 1964). This is necessary to establish the reservoir of energy necessary to combat body heat loss. Onset of cold stress will otherwise be accelerated. In general, divers will perform better in cold water if they are in good physical condition and have adequate rest and nutrition for a week or so prior to diving operations. Breakfast on diving days should consist of foods with high carbohydrate content but low amounts of residue because defecation is rather inconvenient for a suited-up diver. Intake of candy and honey may be beneficial; however, avoid foods and eating habits that might produce nausea.

Water temperature and dive duration are two important factors in the selection of diving dress. Although specially designed wet suits have been used for SCUBA diving under arctic conditions, dry-type suits are recommended for long-duration dives when the water temperature is below 50° F or if the diver is to remain relatively immobile. A relatively inactive diver in a 3/16-in., wet suit will maintain thermal balance for

Figure 4-8. Open-Circuit, Hot-Water Diving System: (a) Hot-Water Suit (Photo by Somers)



(b) Hot-Water Heater and Control Panel (Photo Courtesy of Hot-Water Unlimited)

prolonged periods only if the water temperature is above 70° F. *When possible, use surface-supplied, hot-water circulating suits or variable-volume dry suits.* The selection and design of wet suits for various temperature ranges has been discussed previously.

The diver must be provided with a warm, sheltered area for dressing and should avoid exposure as much as possible prior to the dive. Chilling the diver prior to the dive accelerates the onset of cold stress. If the diver must be transported to the dive site or is to be exposed to surface cold conditions, he must be provided with a heavy parka or insulated exposure suit and insulated overboots. The diver should be protected from exposure between repetitive dives. This is extremely important if he is wearing a wet suit. Never commit a chilled diver to a repetitive dive.

Hot water carried in insulated containers is extremely beneficial for self-contained divers using wet suits. Hot water injected into the diver's suit through the neck opening, mitts, and boots prior to the dive warms the diver and delays the onset of chilling. Similar postdive, hot-water injection rapidly restores warmth to hands and feet and rewarms the diver. Care must be taken not to scald the diver.

Underwater, the diver should avoid excessive movements that tend to increase the flushing of water in and out of his wet suit. Maintaining a reasonable level of exercise produces heat and delays the onset of cold stress. Immobility accelerates chilling. For safety purposes, the diver should terminate his dive with the onset of involuntary shivering and/or diminished manual dexterity.

When the diver surfaces, remove breathing apparatus, weight belts, and fins. Immediate injections of hot water into wet suit, mitts, and gloves are beneficial; do not remove mitts in cold air until hands can be dried and warmed. If there is to be considerable delay in undressing, remove mitts, dry hands, and don wool or insulated mittens. Vigorous exercise will promote warming. The diver should dress-out, have a hot shower, and don dry clothing as soon as possible.

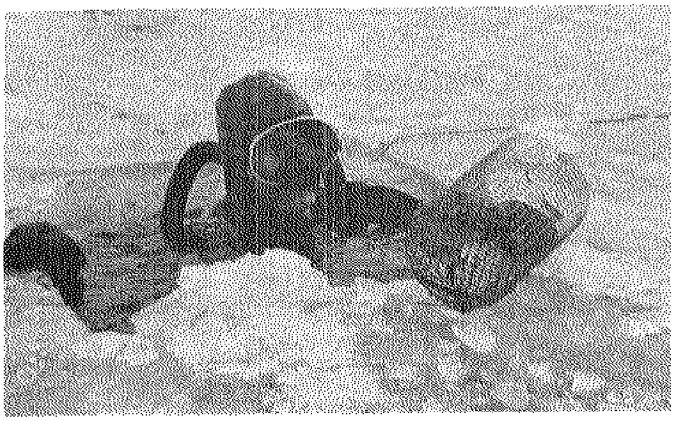
The use of a variable-volume dry suit is extremely beneficial when periods of surface exposure are necessary.

4.4.9 Diving Under Ice

Diving under ice is particularly hazardous and should only be undertaken when absolutely necessary. The diver is subjected to severe cold stress, emergency procedures are complicated, and the SCUBA may be adversely affected by severe cold. In fact, the use of open-circuit SCUBA for diving under ice is discouraged. The effects of cold on SCUBA regulators are discussed in Chapter 6. University of Michigan research divers use surface-supplied diving techniques for under-ice work.

In addition to previously discussed procedures, the following should be considered when working under ice:

- Use ample protective clothing and do not commit a chilled diver to an under-ice mission.
- Always have a stand-by diver ready to enter the water immediately.
- Cut a hole large enough to accommodate 2 or 3 divers even though one diver is under the ice at a time. (Be sure to mark the hole clearly following ice diving to warn fisherman and snowmobile riders of the hazardous opening.)
- Limit dive duration and provide sufficient facilities for immediate warming.
- Never rely on a compass; the safety line or umbilical hose is the only way to insure relocation of the hole.
- The safety line must be secured to the diver, not his equipment. A *trained* tender must handle the safety line or umbilical hose. Secure the line to a fixed object on the surface.
- Avoid long excursions under the ice. If it is necessary to cover large areas when under the ice, cut several holes and make a series of dives.



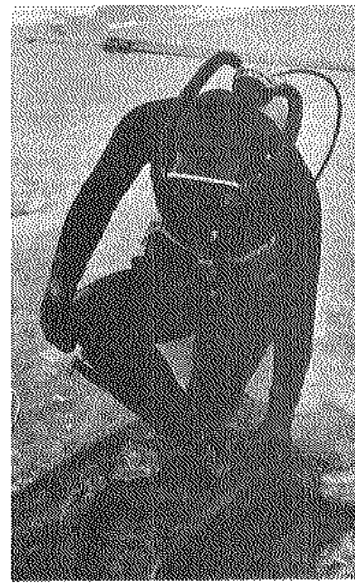


Figure 4-9. Divers Preparing to Collect Samples Under Ice-Covered Michigan Lake (Though SCUBA has been used for under-ice diving by most researchers, surface-supplied equipment is currently recommended at The University of Michigan.)

- Avoid having more than one surface-supplied diver or one SCUBA team in the water at a time.
- Divers must have considerable open-water experience prior to diving under ice.
- If SCUBA is used, use only two-hose regulators and carry an auxiliary breathing unit. Do not inhale from regulators above water, wait until you submerge.

Additional information on diving under ice is given by Ray and Lavallee (1964).

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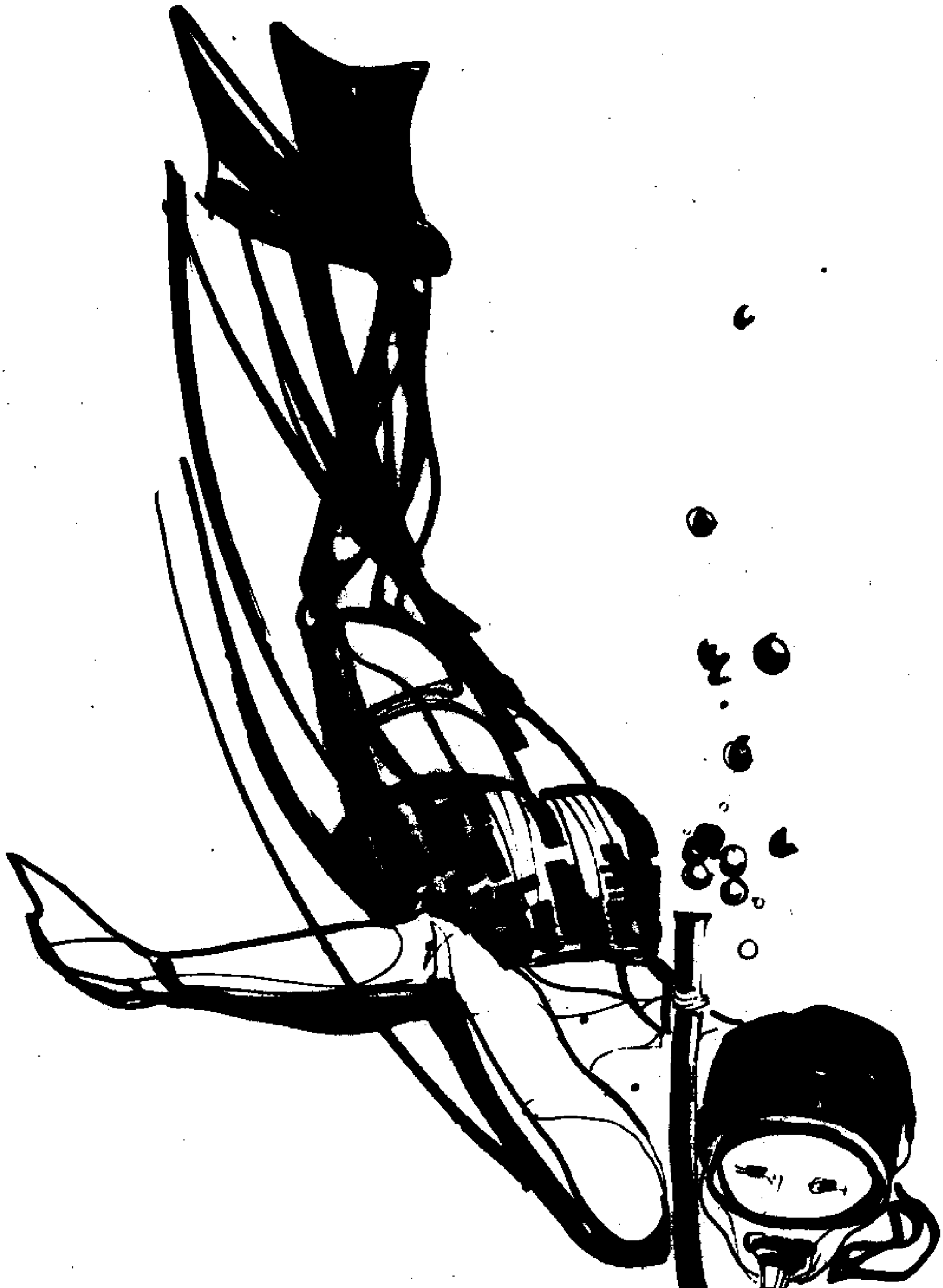


5 DIVING WITHOU BREATHING APPARATU

5.0 Diving Without Breathing Apparatus

Emphasis on diving with SCUBA should not obscure the importance of diving without respiratory equipment. Frequently the research diver will be required to recover specimens, photograph, or make observations in shallow water without the aid of SCUBA. A physically fit, veteran diver will generally be capable of breathhold dives to depths of 40 ft or more. Conditioned spearfishermen or persons who make breathhold dives frequently may dive to depths exceeding 90 ft. The current record breathhold dive is to a depth in excess of 240 ft.

Breathhold diving or skin diving is a necessary part of training for diving with SCUBA. Proper use of mask, fins, or snorkel, surface swimming, surface dives, underwater swimming, pressure equalization, and rescue techniques are all necessary skills required for mastering SCUBA diving. Furthermore, skin diving on shallow coral reefs can provide endless hours of pleasure.

Breathhold diving is not without hazard. The diver must be an excellent swimmer and in reasonably good physical condition. An enthusiastic skin diver will frequently expose himself to more adverse conditions and greater physical strain than the casual swimmer. He will venture farther from shore under more hazardous environmental conditions for longer durations. The skin diver is subject to barotrauma of the ears and sinuses as any other diver; however, air embolism and related complications are only a problem if the diver breathes air while underwater from SCUBA, a habitat, an air pocket under a rock ledge, etc. Since breathholding can cause serious problems, the diver must thoroughly understand the potential hazards of prolonged breathholding under pressure. Physiological aspects of breathholding and submergence are discussed in Chapter 3.

The basic equipment for breathhold diving includes a mask, a snorkel, a pair of swim fins, and a *lifejacket*. These items are discussed in the section on "Accessory Equipment" in Chapter 6. The diver may use a weight belt to achieve a state of near-neutral buoyancy on the surface. Actually the diver should have slight positive buoyancy at the surface. He should never wear sufficient weight to cause him to sink. Information on skin diver training and skills is given by Empleton (1968).

5.1 Donning Face Mask, Swim Fins, Snorkel, and Lifejacket

The *face mask* should fit the diver's face comfortably and hold its position on the face when the diver evacuates air from inside the mask by inhaling through his nose. If during inhalation, air leaks into the mask or the mask fails to hold to the diver's face, it either does not fit or there is some material such as hair, wet-suit hood, or mask strap preventing the entire edge of the mask from sealing. Prior to diving the face plate should be coated with an antifog compound such as saliva, dishwashing soap, or a commercial preparation. Fogging underwater may be removed by admitting a small quantity of water into the mask, rinsing the face plate, and purging the water from the mask. Some divers even retain a small volume of water in their masks for this purpose throughout the dive. The mask strap should be periodically inspected for signs of wear and adjusted so that the mask fits comfortably and snug, but not tight. A tight-fitting mask may cause discomfort or a headache, and a loose-fitting mask may easily be lost.

Prior to donning the mask, the diver should wet both the mask and his face to improve the sealing action. Then the mask is grasped by the faceplate retainer, positioned on the face, and secured by placing the strap behind the head. Generally the diver uses both hands for this procedure; however, donning the mask completely with only one hand must also be mastered. Test the seal by inhaling through the nose. Always hold the mask to the face when jumping into the water.

The selection of *swim fins* is based on fit, physical condition, and mission requirements. Prior to each dive, the fins, particularly the adjustable heel straps, are checked for signs of wear or damage. Adjustable straps and buckles must be secure. To facilitate donning, wet both the fin and foot. Grasp the fin by the side rib at the instep and slide onto foot. Then position the heel strap. Don't don fins by pulling on the heel strap or back of the foot pocket on shoe-type fins; this frequently damages the strap or foot pocket. Shoe-type fins may be more easily donned by turning the back of the foot pocket under the fin (inside out), sliding the fin onto the foot, and flipping the back of the pocket into place.

For breathhold diving, the *snorkel* is generally secured to the mask strap by a small rubber retainer. Prior to use, the snorkel should be inspected and cleared of foreign material (insects, sand, etc.), if necessary. To don, insert the mouthpiece into the mouth with the flange between the teeth. Adjust the retainer so that the snorkel is comfortable in your mouth, and the tube points slightly to the rear when the face is in the water in swimming position (looking down and slightly forward). The *lifejacket* should be inspected prior to each dive to ensure that the gas cylinder is full, the activator is functioning properly, and that there are no tears or leaks. Don the lifejacket and secure with the straps. The straps should be snug and comfortable, but not tight enough to induce restriction when breathing deeply.

5.2 Swimming with Fins

The kick used almost exclusively by skin and SCUBA divers is a modification of the standard flutter-type kick used by swimmers. Since swim fins greatly increase the efficiency of the flutter kick, the diver's version of this kick is much slower and the feet travel through a wider arc. The kick action is from the hip, with pointed toes and slight flexure in the knees. When used on the surface, the fins should not break the surface of the water throughout the entire motion. The body should stay relatively straight. If the hips tend to buoy up the legs, resulting in the feet breaking the water surface continuously, or if there exists a necessity of bending at the hips to keep the feet under, the diver should swim with his body straight but tilted downward at a slight angle to the water surface. A weight belt may be required to overcome hip buoyancy. Underwater the diver should relax and may increase the arc of the kick. The legs may have to be spread slightly to avoid fins touching. Do not stiffen the knees, and avoid excessive body roll. Maintain a slow, steady rhythm. The diver should avoid excessive use of hands when swimming on the surface or underwater; he should trail them in a relaxed fashion at his side.

5.3 Surface Diving Techniques

The breathhold diver or skin diver swims on the surface and breathes through a snorkel until he is ready to submerge. At this time he ventilates his lungs a few times, takes a full breath of air and executes a head- or feet-first surface dive. The head-first (jack-knife) surface dive is performed by bending the body at the waist, thrusting the trunk well down, and bringing the legs out of the water into a vertical upward position. The weight of the legs above water should be sufficient to thrust the body downward; no other movement should be necessary until the fins are fully submerged. Then continue downward motion by kicking. As soon as the diver submerges, he should start equalizing pressure in his ears as explained in Chapter 3.

Some divers prefer the feet-first surface dive. The diver prepares for the dive as above; however, to execute the dive, he drops his feet and assumes an upright vertical position with his head above the water. He then kicks strongly with his fins and at the same time brings his hands sharply to his sides. This action raises part of the diver's upper body above water. Now the toes are pointed, the diver relaxes, and drops vertically underwater. When submerged, turn on face or side and kick downward.

5.4 Using the Snorkel

The snorkel is positioned on the mask strap so that it is comfortable and not submerged during surface swimming. A normal breathing rhythm and volume exchange should be maintained. Avoid repeated hyperventilation or "skip" breathing (holding breath for long periods between inhalations). When the diver submerges, the snorkel will partially fill with water; however, in most cases, the entrapped air and pressure equalization will keep water from entering the diver's mouth.

During ascent, look up toward the surface and rotate the body 360 degrees to check for overhead obstructions. Keep the face pointed upward so that the top of the snorkel is slanted downward. Gently expel air into the snorkel while coming up. Because of the downward slant, the air will remain trapped in the tube and displace all the water. Start exhalation approximately 2 ft from the surface. When you reach the surface, simply roll into a swimming position and resume breathing. Since you exhaled underwater, cautious inhalation will bring fresh air upon reaching the surface.

5.5 Entries

Whenever possible, skin and SCUBA divers should enter the water from a diving ladder or by jumping feet first from a low platform. A basic factor to remember when performing all jump or roll entries is to hold the face mask to the face to prevent loss. Some divers prefer to hold the bottom of a SCUBA cylinder against the back to minimize the possibility of hitting the head with the regulator. This is generally not necessary if the SCUBA is designed and fitted properly. The following entries should be mastered by skin divers (without SCUBA); they will later be used for SCUBA diving.

An excellent method of entering the water from a low platform is to simply sit on the platform with the feet in the water, hold the mask to the face, tuck chin, and *roll forward* in a somersault fashion. The shoulder or SCUBA cylinder will hit the water first.

The *step-in or stride entry* is used from a dock, platform, or boat dock. Hold the mask firmly against the face and look straight ahead. In a smooth motion, bend slightly forward at the waist and step off with a wide stride; do not look down. As the body strikes the water and starts to submerge, make a sharp scissor-type kick and sweep free arm downward. This entry resembles the standard feet-first lifesaver's entry.

When working from small boats, it is generally desirable to sit on the gunnel with the back to the water and feet in the boat. To enter, simply press the mask to the face, tuck chin, and *fall backwards*. The SCUBA cylinder will strike the water first.

5.6 Reference

Empleton, B. (ed.), *The New Science of Skin and SCUBA Diving*, 3rd rev. ed. (New York: Association Press, 1968).

6 SELF-CONTAINED DIVING

6.0 Self-Contained Diving

6.1 Introduction

Self-contained underwater breathing apparatus (SCUBA) (Figure 6-1) was developed to facilitate complete freedom of movement underwater. The diver carries his breathing medium with him, thus allowing him to operate independent of surface support and with freedom from the encumbrance of the umbilical hose required for surface-supplied diving apparatus. Three major categories of SCUBA are currently in use:

1. Open-circuit demand

   Compressed air
   Cryogenic (primarily experimental)

2. Semiclosed circuit (mixed-gas application)

3. Closed circuit

   Pure oxygen
   Mixed-gas
   Cryogenic.

Open-circuit, demand-type SCUBA is the simplest type and the one most frequently used by divers. Only open-circuit, demand-type SCUBA will be discussed in detail.

The diver must know and appreciate the difference between self-contained diving (open circuit: air) and surface-supplied diving so that he can choose the proper equipment for a specific mission. The best way to compare these two types of diving is to consider the advantages and disadvantages of SCUBA.

- Advantages of Open-Circuit SCUBA:

  1. mobility,
  2. portability,
  3. adaptability to small-boat operation (requires minimum support equipment),
  4. readily available training to most research personnel.

- Disadvantages of Open-Circuit SCUBA:

  1. limited depth,
  2. limited duration (air supply),

Figure 6-1. Diver Equipped with Open-Circuit Self-Contained Underwater Breathing Apparatus (Photo by Somers)

3. limited exertion,
4. inefficient for most diving missions,
5. limited communications capability,
6. limited thermal protection for self-contained divers,
7. requires a minimum of two divers for safety purposes,
8. relatively unsafe for limited visibility diving conditions.

Recent field experience has shown that open-circuit SCUBA has definite limitations and that for many missions surface-supplied diving techniques may increase operational efficiency by as much as a factor of four. However, at present, open-circuit SCUBA is still the "standard" diving apparatus for research-diver applications. The advantages and disadvantages of surface-supplied diving will be discussed later.

6.2 Open-Circuit SCUBA

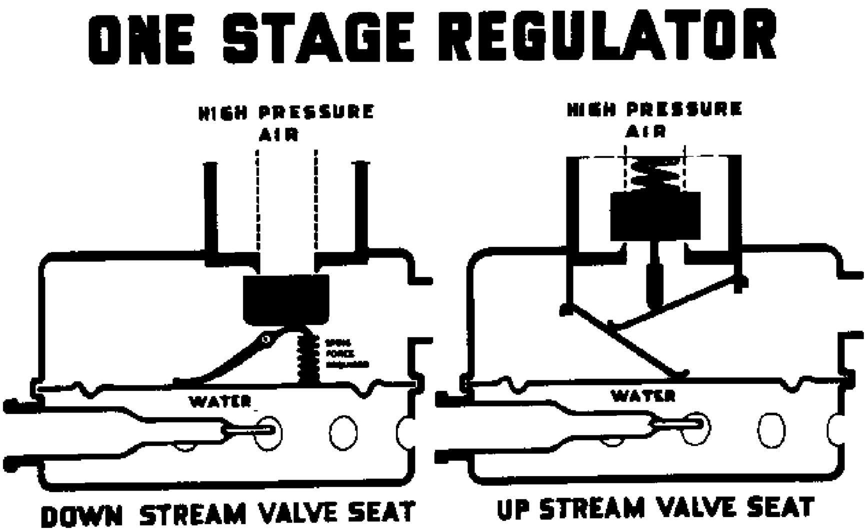
6.2.1 Demand-Type SCUBA Regulator

The demand regulator is a mechanism which reduces the high-pressure air in the cylinder to ambient or breathing pressure. The volume of air delivered is regulated by the diver's inspiratory requirements. In open-circuit demand SCUBA, the diver inhales air from the air cylinders and exhales directly into the surrounding water; in a properly designed apparatus, no gas is rebreathed. Demand regulators are available in both one- and two-reduction-stage types.

In the discussion of regulator valve systems, the terms "upstream" and "downstream" are frequently used (Figure 6-2a). *Downstream* refers to a valve which is forced open by the high-pressure air. Consequently, a mechanical force such as a spring must counteract the force of the high-pressure air. A downstream, high-pressure valve spring is calibrated to hold the valve closed against a full cylinder pressure and, consequently, offers greater mechanical resistance to opening at a low cylinder pressure. In the *upstream*-type valve, the opposite is true. The high-pressure air closes the high-pressure valve and as the cylinder pressure drops, the valve offers less resistance to opening.

6.2.2 One-Stage Demand Regulator

The one-stage demand regulator (Figure 6-2a) is designed to reduce air at cylinder to ambient pressure through one reduction stage. Inhalation lowers the pressure in the air chamber and the flexible diaphragm is deflected inward by the higher water pressure. This movement activates the lever system to open the



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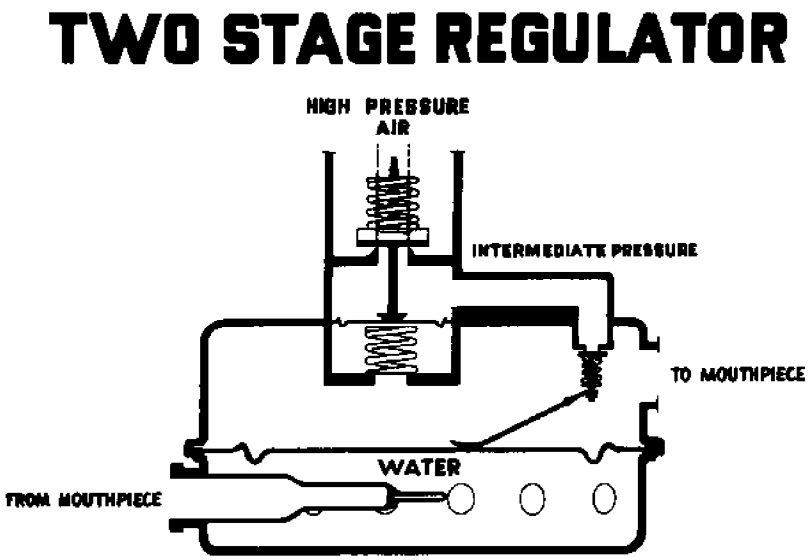

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Figure 6-2. Cross-Section of Common Double-Hose Regulators: (a) One-Stage Regulator, Including Diagram of Upstream and Downstream Valve Seats; (b) Two-Stage Regulator (Photo Courtesy of US Divers Co.)

high-pressure valve. Air flows from the cylinder until the demand ceases; the pressure in the air chamber is then equal to ambient and the high-pressure valve closes.

This regulator is commonly available only in double-hose models. It is rugged, has a limited number of moving parts, and is relatively easy to maintain and repair. However, breathing resistance increases with high air flow requirements at greater depths and there is a slight variation in flow with changing cylinder pressure.

6.2.3 Two-Stage Demand Regulator

The two-stage demand regulator, available in both single- (Figures 6-3 and 6-4) and double-hose (Figure 6-2b) models, is designed to reduce the high-pressure air from cylinder pressure to ambient pressure through two reduction stages. In double-hose models, the pressure reduction mechanisms are housed as a single unit which attaches to the cylinder valve. However, in single-hose models, the first- and second-stage reduction mechanisms are separated by a length of hose, and the second stage is part of the mouthpiece assembly.

The first stage is depth compensated and designed to maintain a constant intermediate pressure of 110-130 lb/in^2 above ambient pressure, depending upon the make of regulator. Three types of intermediate-pressure reduction valve systems used in SCUBA regulator first stages are described later. The second stage is a demand-lever-activated unit designed to reduce the intermediate pressure to ambient pressure. Inhalation by the diver causes a pressure reduction within the second-stage air chamber with respect to ambient pressure and a flexible low-pressure diaphragm is deflected inward. This activates the second-stage demand lever which opens the low-pressure valve assembly and allows air to enter the second-stage chamber until demand ceases and the internal pressure equals ambient pressure. As air is released from the intermediate-pressure chamber, the high-pressure valve opens and allows air to enter the intermediate-pressure chamber from the cylinder. When pressures are balanced, the valves close to stop air flow until the next inhalation. In single-hose regulators, the low-pressure diaphragm may be depressed manually to activate the demand lever and start air flow.

First-stage reduction valves are available in standard, balanced, and piston types. In the *standard first-stage assembly* (Figure 6-3d), the high-pressure cylinder air acts to close the valve. Counteracting the closing force of the cylinder air is a large spring pressing against a high-pressure diaphragm, which is coupled

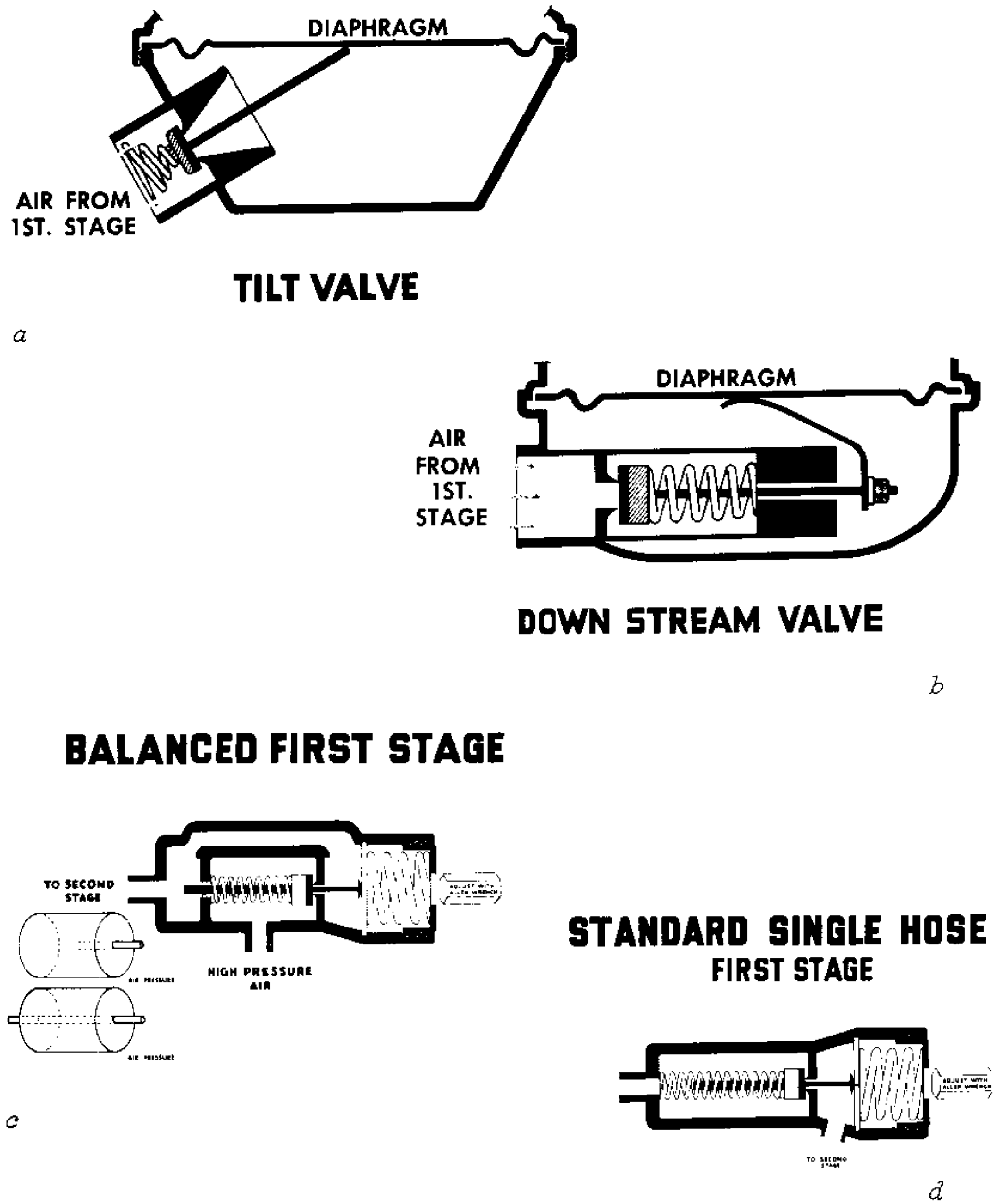
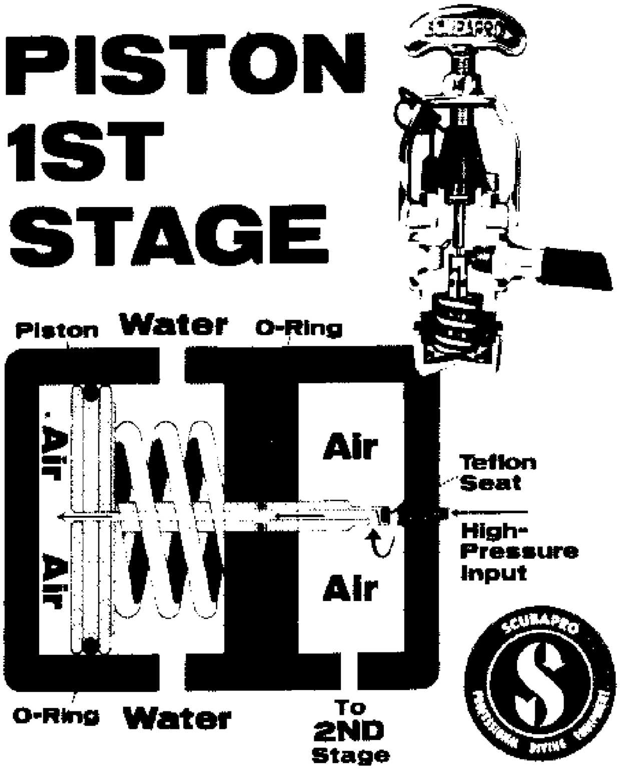


Figure 6-3. Cross-Section of Single-Hose Demand Regulators: (a) Tilt Valve, Second Stage; (b) Downstream Valve, Second Stage; (c) Balanced First Stage; (d) Standard First Stage (Photo Courtesy of US Divers Co.)



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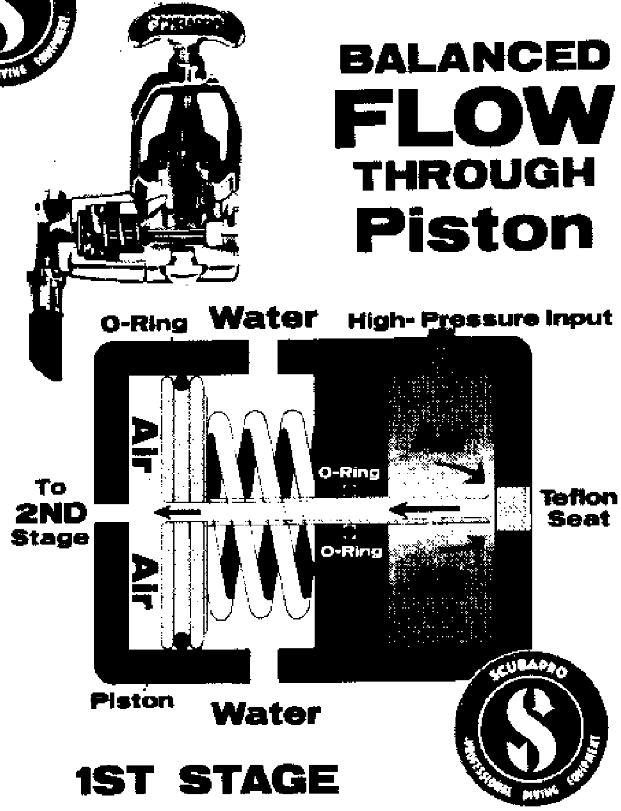

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Figure 6-4. Cross-Section of Piston-Type First Stage: (a) Standard Piston Type; (b) Balanced Flow Through Piston Type (Photo Courtesy of SCUBAPRO) to the high-pressure valve seat assembly. Movement of the diaphragm moves a stem to open or close the valve seat assembly. The heavy spring is manually adjusted to hold the valve seat assembly open until the intermediate pressure increases to a predetermined level. The first stage is depth compensated by water or air pressure exerted on the high-pressure diaphragm.

The delivery efficiency of the mechanism varies with cylinder pressure. The small diaphragms used in single-hose regulators are extremely sensitive to fluctuations in pressure and, consequently, slight pressure variations can have marked effects on air-flow capacity and breathing effort. To reduce the amount of variation caused by cylinder pressure differences, it is necessary to reduce the size of the inlet orifice. Unfortunately, a small orifice adds resistance to air flow and, therefore, breathing, when high air-flow volume is required. Thus the standard first stage has definite air delivery limitations under high flow requirements, especially at depth.

In comparison to the standard first stage, cylinder pressure has no effect on the seating of the high-pressure valve assembly in the *balanced first stage* (Figure 6-3c). In the balanced valve, a valve stem of approximately the same size as the orifice is extended outside the high-pressure chamber. Therefore, high pressure is not exerted on the end of the valve stem. With the cylinder air pressure neutralized, only the mechanical forces of the springs affect the operation of the valve. These springs can be set at the exact, desired, intermediate pressure and do not vary with changes in cylinder pressure. Consequently, large orifice diameters can be used, and the breathing resistance produced by moving air through a small orifice is eliminated. This first stage is designed to enclose the entire valve assembly for protection against saltwater corrosion and foreign material, yet maintain depth compensation. The balanced first stage is used in most high-performance regulators.

The *piston-type first stage* (Figure 6-4) is a simple and functional unit with only one moving part--the piston. This is probably the most common first stage currently used in single-hose regulators. It is currently not used in double-hose regulators. By using a precision-ground spring of proper compression, the desired intermediate pressure can be maintained with no further adjustment. As the system is pressurized, air flows through a small hole, located in the side of the piston stem just behind the soft seat, up through a bore in the piston stem and pressurizes the air space between the cap and the large end of the piston (Figure 6-4b).

In the balanced flow-through piston model (Figure 6-4a), air enters the open end of the piston and a soft seat is embedded in the case just below the end of the piston. This force acting on the larger area of the piston is greater than the force at the small end due to the differential in surface areas. Consequently, the piston moves toward the small end.

This piston is depth-compensated through application of hydrostatic pressure to the spring side of the piston by admitting water into spring chamber. In this manner the intermediate pressure always remains at a predetermined level above ambient pressure. When this pressure is reached, the piston moves downward, and the air flow from the cylinder is stopped by the closing of the valve. As the diver inhales,.the intermediate air pressure is subsequently reduced, the piston moves upward, and air flows through the regulator until the diver stops inhaling and the predetermined intermediate pressure is again reached.

Since the operation of the piston depends on the seal of the two "O"-rings, damage to either of these rings or the very smooth bores due to sand or salt crystals can result in malfunction.

6.2.4 Exhaust Valves

In double-hose regulators, air is exhaled through a nonreturn valve located in the mouthpiece assembly into the exhalation hose where it is channeled to the open-chamber portion of the regulator case. A nonreturn valve at the end of the exhalation hose permits air to escape but prevents water from entering the exhalation hose. The exhaust valve is located in the regulator case to minimize exhalation resistance by placing the exhaust valve at a lower pressure than the lungs when the diver is in normal swimming position. High exhalation resistance results in greater respiratory fatigue over long durations than equivalent inhalation resistance.

The exhaust valve port in a single-hose regulator is located in the lower portion of the second-stage air chamber (mouthpiece assembly). A nonreturn valve prevents water from entering through this port. The exhaled air is deflected away from the diver's face through a special rubber assembly. Until recently, most single-hose regulator exhaust valve ports were small enough to cause significant exhalation resistance. Most current models are designed with larger exhalation valve ports to minimize this resistance.

6.2.5 Thermal Reaction

In cold climates and/or cold water, *internal freezing* of regulators may result from moisture mixed with the cylinder air. In this case, cooling of the air due to expansion from high pressure to low pressure causes moisture in the air to freeze. Consequently, ice crystals may plug the orifices in any regulator and cause malfunction. Single-hose regulators appear to be extremely susceptible to ice-crystal problems and are not recommended for extremely cold-water diving operations. Recently, both University of Michigan and US Navy divers experienced single-hose regulator malfunctions in the arctic. The regulators froze in a free-flow position. Obvious problems were precooling of the regulator by exposure to extreme cold prior to the dive and residual moisture introducted during rinsing. Breathing from the regulator in a subfreezing atmosphere prior to submergence also adds to the freezing probabilities. Based on these results, the US Navy has recommended that all diving with open-circuit SCUBA in water colder than 38° F be conducted with double-hose regulators (Anonymous, 1971). Only *moisture-free* air should be used for cold-water diving operations.

External freezing may occur when single-hose regulators are used in water at temperatures near freezing (32° F). Ice crystals have been observed to form around both the first- and second-stage assemblies. These ice crystals may plug openings and interfere with the movement of regulator parts, causing either loss of depth compensation, free flow, or restricted breathing.

The primary reason for *external freezing* in single-hose regulators is the small size of the regulator case exposed to the water. Expansion of cylinder air from high pressure to low pressure absorbs heat from the surrounding metal and, consequently, reduces the temperature of the metal. When it is immersed in water already near the freezing point, the reduction in the temperature of water in contact with the metal causes freezing. The ice crystals may build up rapidly to plug orifices in both the first and second stages of the regulator.

In two-hose regulators the high-pressure reduction mechanism is somewhat protected from contact with the water by the large metal case. Also, the larger mass of metal affords a better heat transfer. Two-hose regulators are less likely to malfunction from internal and external freezing.

6.2.6 COMPRESSED-AIR CYLINDER

The compressed-air supply for open-circuit SCUBA is contained in steel or aluminum-alloy cylinders. Aluminum cylinders, not bearing a Department of Transportation (DOT) approval stamp, are generally restricted to European countries and United States military applications. US Navy cylinders are constructed of materials which comply with low magnetic effects (μ) requirements to facilitate operations around magnetic mines. Cylinders for civilian use generally have a rated working pressure of 2250 lb/in^2 and a normal internal volume of 730 in^3. When charged to 2250 lb/in^2, a standard cylinder contains approximately 64.7 ft^3 of free air. The 71.2 ft^3 capacity is at 10 percent over working pressure (2475 lb/in^2) allowable under Department of Transportation (DOT) specifications, as indicated by a plus (+) symbol adjacent to the initial hydrostatic test date stamped near the cylinder neck. Cylinders with free air capacity (at 10 percent over pressure) of 26, 38, 50, 52.8, 75, and 100 ft^3 are also available. Open-circuit SCUBA is available in 1-, 2-, or 3-cylinder assemblies.

Recently, the Department of Transportation has approved a 71.2 ft (2475 lb/in^2) aluminum-alloy cylinder for general use in the United States. The corrosion resistance properties of this aluminum alloy are far superior to steel; consequently, both internal and external corrosion problems are minimal. These new cylinders, distributed by the US Divers Co., are longer and more buoyant (3.75 lb positive when full and 9.5 lb positive when empty) than steel cylinders of equal capacity. For more detail, see McKenny (1972).

The exterior of the cylinder is protected against rust and corrosion by galvanized metal, epoxy paint, or vinyl-plastic coating. Galvanized exteriors are recommended for durability against abrasion. Epoxy paint or plastic over zinc-galvanized surfaces prevents electrolytic corrosion of the zinc by salt water. However, with proper preventive maintenance electrolytic corrosion is relatively insufficient.

High-pressure cylinders are stamped with letters, numbers, and symbols near the neck, giving certain specifications. The following is an example of the markings found just below the neck of a standard SCUBA cylinder:

DOT 3AA2250

K7422

USD

1(L 70+ .

The DOT designates that the cylinder is acceptable for interstate transport in accordance with DOT specifications. Cylinders manufactured prior to January 1970 may read ICC (Interstate Commerce Commission) in lieu of DOT; the change to DOT resulted from governmental reorganization and an amendment to the hazardous materials regulations. The type of metal alloy used in manufacturing is designated by 3AA or 3A, indicating chrome molybdenum alloy and carbon steel alloy, respectively. The rated working pressure, 2250 lb/in^2, follows the material designation. In the above example, K7422 is the cylinder serial number, and USD is the distributor's symbol. The hydrostatic test date is indicated by 1 (L 70+, where (L) is the registered symbol of the tester and the (+) following the test date designates that the cylinder may be charged to 10 percent over the rated working pressure.

The bottoms of SCUBA cylinders are often fitted with a rubber or plastic boot for protection and to facilitate holding the cylinder in an upright position. Boot-equipped cylinders should not be left unattended in an upright position. The boot should also be removed periodically to inspect for corrosion; preventive measures may be required.

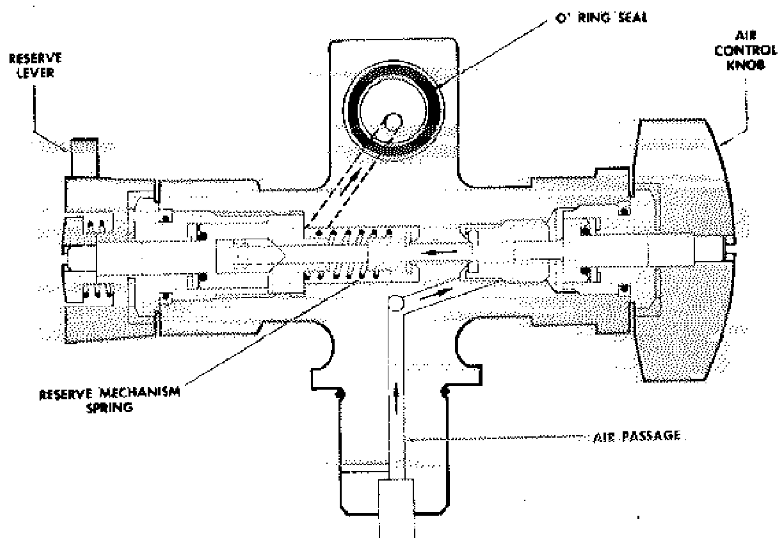
6.2.7 Cylinder Valve Assembly

The cylinder valve assembly is primarily a shutoff valve to control the flow of air from the SCUBA cylinder and is designed to facilitate attachment of a demand regulator or cylinder filling device. Most open-circuit valve assemblies have a thin, metallic safety disk which is designed to rupture at 3000 lb/in^2 cylinder pressure as a measure to prevent cylinder damage from excessive pressure. The assembly may also include a spring-loaded, low-pressure air warning mechanism (Figure 6-5). The shutoff valve may be incorporated into manifold units for use with multiple-cylinder SCUBA.

6.2.8 Low-Pressure Warning Device (Reserve)

All open-circuit SCUBA must be equipped with a positive warning system to alert the diver that his gas supply is critically low. The system may be a valve mechanism, an audible signal device, a calibrated orifice, or a pressure readout gauge. Warning systems may be incorporated into the regulator assembly or cylinder valve.

The most common mechanism is a pressure relief valve with a manual override. This type is generally referred to as a *spring-*



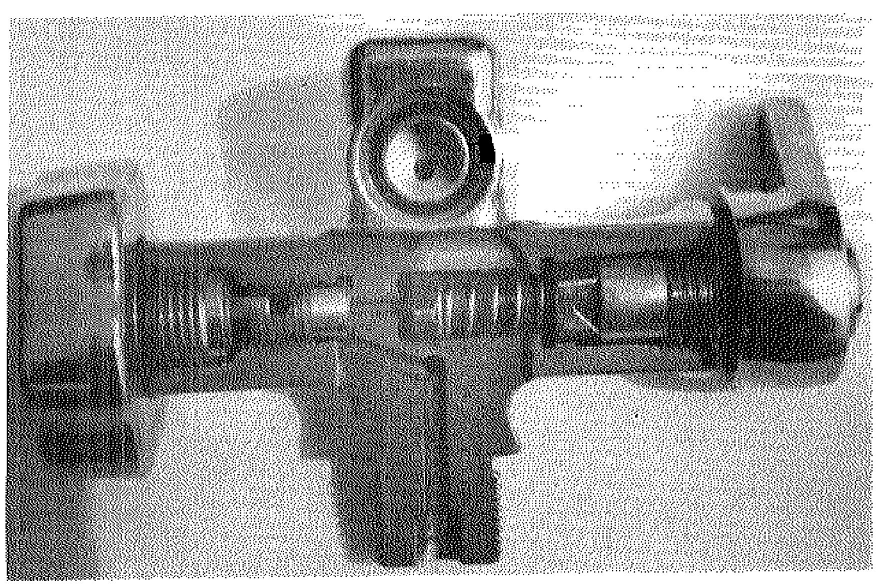


Figure 6-5. Spring-Loaded Low-Pressure Air Warning Mechanism (Cross-Section Diagram Courtesy of US Divers Co.; Photo by Somers)

loaded reserve (Figure 6-5). This mechanism permits a free flow of air to the regulator until the cylinder pressure falls to a predetermined level (approximately 300 lb/in^2 for single-cylinder SCUBA and regulator; 500 lb/in^2 for two-cylinder SCUBA). At this pressure, a spring forces a flow check against the port orifice and restricts the air flow, causing increased breathing resistance. This is followed by total obstruction of air flow.

The remaining air may be released by manually overriding the check valve. The diver activates a reserve lever, which advances a plunger pin and pushes the flow check off of the orifice against the action of the spring or retracts the plunger. The entire reserve air supply is available to the diver. Unfortunately, this reserve lever may be accidentally activated during the dive or the diver may fail to place it in a proper position prior to the dive. In either case the diver may completely exhaust his air supply at depth without warning.

The *audible low-air warning system* is probably the most foolproof mechanism used in SCUBA since it eliminates the human error possibility of neglecting to properly position the reserve mechanism and the possibility of accidental activation. In this system an audible signal automatically sounds when the cylinder pressure reaches a given level. The signal continues during inhalation until the air supply is exhausted or inhalation ceases. This type of warning mechanism is only in limited production at present, probably due to design, manufacturing, and marketing problems.

The *depth-compensating or restricted-orifice principle* is no longer used on most American SCUBA for low-pressure warning mechanisms. This device operates on the principle that a stream of air will flow through an orifice of a given size in direct proportion to the pressure differential existing on both sides of that orifice. The orifice size is calibrated so that there will be insufficient air flow through the orifice for normal inhalation when the pressure differential is approximately 200-300 lb/in^2. The restriction to air flow is, therefore, dependent also upon depth. Consequently, near the end of the air supply the diver feels a restriction of air flow during inhalation. Direct ascent increases the pressure differential across the orifice and sufficient air should be available for normal ascent.

Once air pressure has dropped low enough, the diver must immediately ascend unless provisions are made in design for by-passing the restrictive orifice. Descent is impossible. If the diver breathes "lightly" and consumption (volume per breath) is limited, he may "breathe past" his reserve supply at shallow depths. In this case air demand is insufficient for the diver to notice significant restriction and he may nearly empty the cylinder(s) before breathing restriction is evident. If under these conditions the demand would suddenly increase, air flow would be insufficient. Also, the restrictive orifice reduces the flow capacity of a regulator even when the pressure differential is high; this greatly reduces the regulator's operational efficiency. Divers are therefore discouraged from using SCUBA equipped with restricted orifice reserve mechanisms.

Some divers prefer to use two cylinders connected by a yoke (Figure 6-6a). The diver opens only one cylinder at the beginning of the dive and upon depletion of that air supply opens the second cylinder. The air equalizes between the cylinders, the reserve cylinder is closed and the diver terminates his dive after he has performed this procedure two or three times. Some divers use two, single SCUBA cylinders with separate regulators mounted in a double-cylinder harness (Figure 6-7c); this method requires switching mouthpieces while underwater.

An *underwater pressure gauge* (Figure 6-7a) is recommended for all SCUBA. This gauge may be connected to all single-hose regulators, some double-hose regulators, or the cylinder valve (not recommended). A special adaptor is available to facilitate use with some double-hose regulators. The high-pressure gauge is fitted with a length of high-pressure hose, which allows it to be positioned so that the diver may constantly monitor his cylinder pressure.

6.2.9 Auxiliary Breathing Systems

Many divers now use regulators with dual second-stage assemblies (Figures 6-7a and 6-7d) to facilitate buddy-breathing. Some single-hose regulator, first-stage assemblies are designed with two low-pressure ports; others require a special adaptor (Figure 6-7b). The auxiliary mouthpiece may be secured to the diver's shoulder harness with a quick-release mechanism.

Cave divers often mount a 12- to 40-ft^3 air cylinder and single-hose regulator on their twin-cylinder SCUBA as an emergency air supply in case of regulator malfunction (Figure 6-7e). During one test, a diver safely returned from 200 ft to a reserve air supply at the decompression stop using this emergency SCUBA. The unit should be securely mounted, and the air turned on prior to the dive.

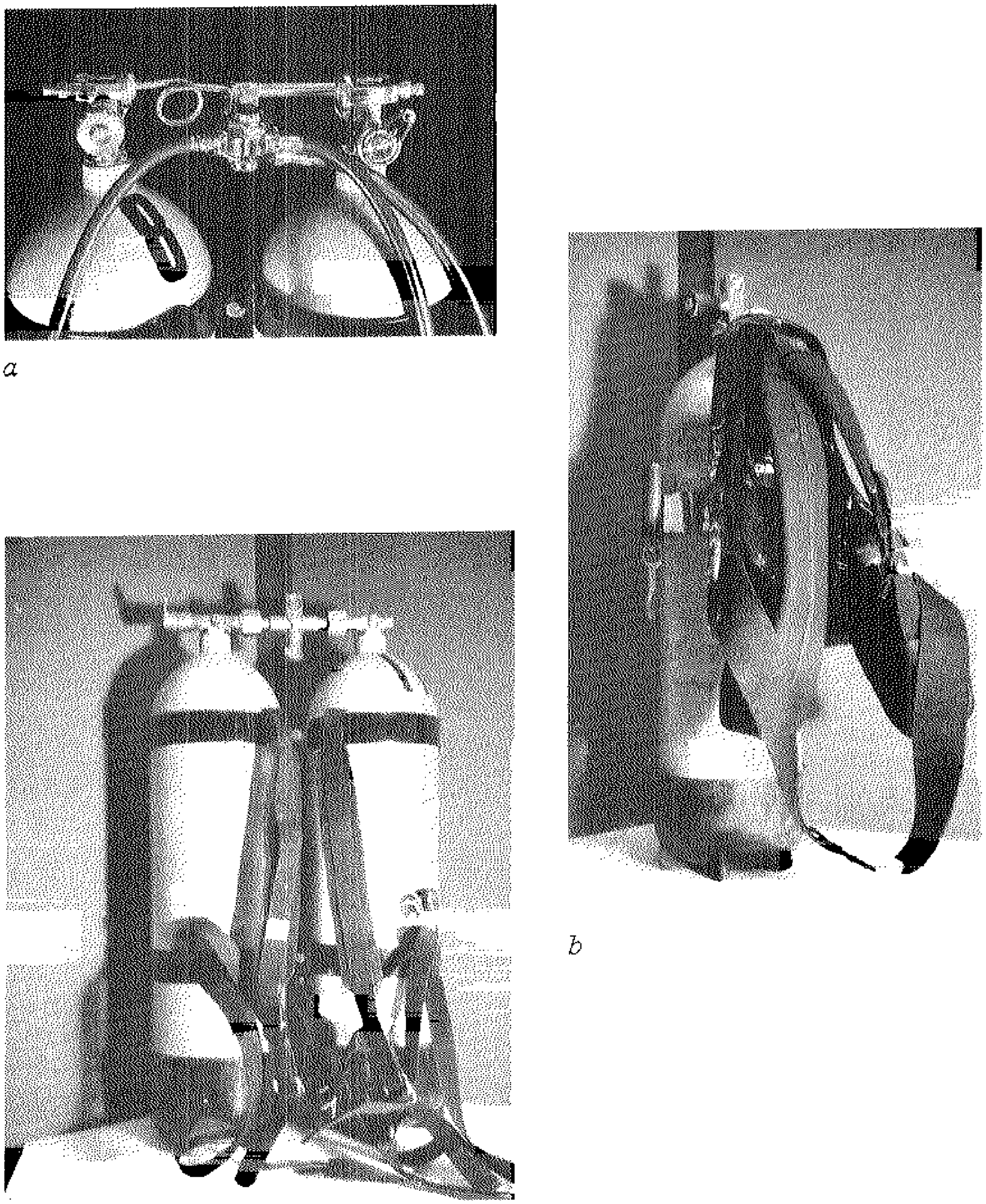


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Figure 6-6. Open-Circuit SCUBA Components: (a) Two Cylinders Connected by a Flexible Yoke Assembly; (b) Contour Backpack for Single Cylinder; (c) Harness and Band Assembly for Twin Cylinders (Photos by Somers)

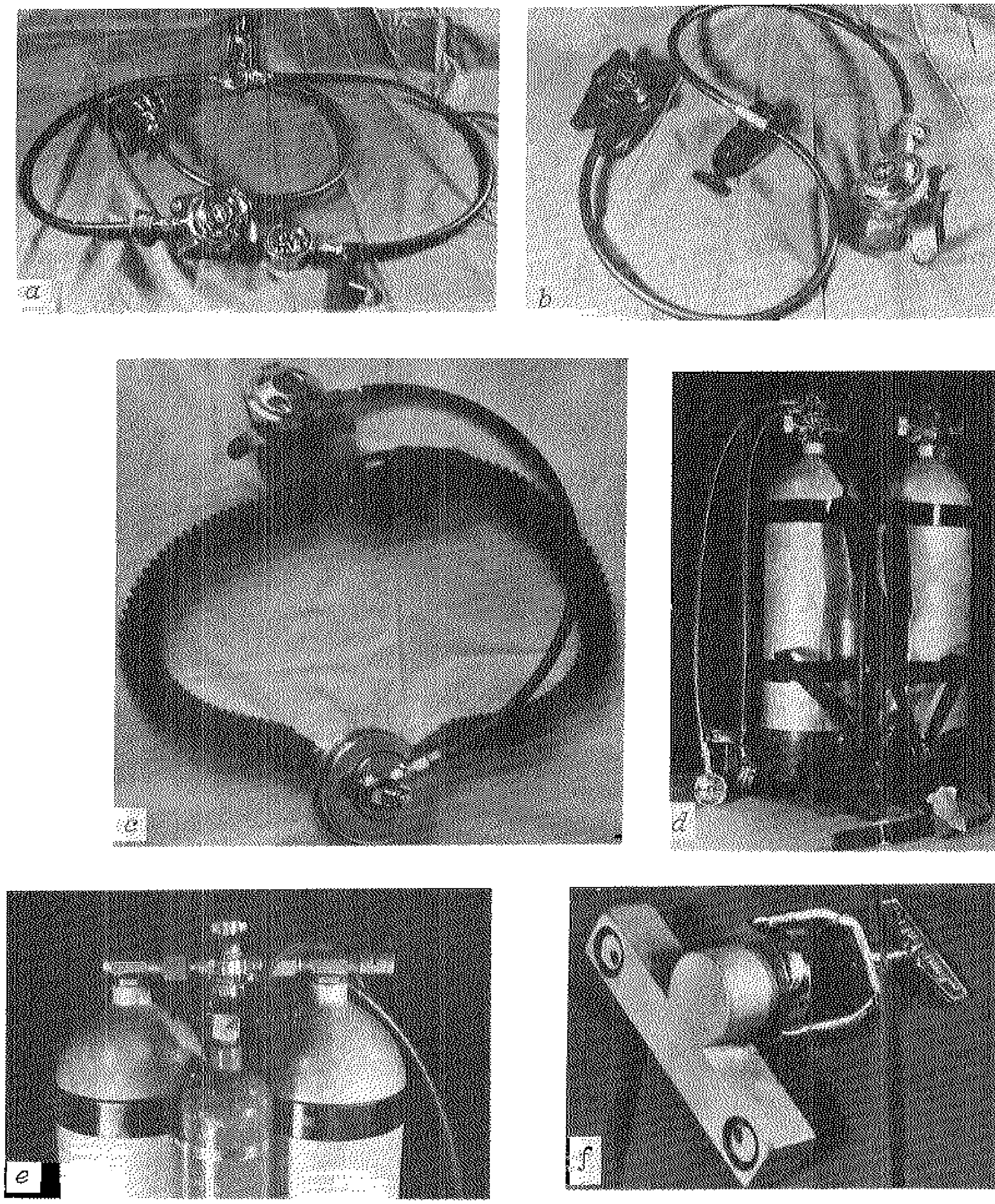


Figure 6-7. Open-Circuit SCUBA Components: (a) Single-Hose Regulator Equipped with an Underwater Pressure Gauge and an Auxiliary Second-Stage Assembly (Octopus); (b) Single-Hose Regulator Equipped with Dual Second Stages Using a Special Adaptor; (c) Auxiliary Second Stage Attached to Double-Hose Regulator (US Diver Aqua Master); (d) Two Single Cylinders with Separate Regulators in a Double Cylinder Harness; (e) Separate Emergency SCUBA Attached to Twin-Cylinder SCUBA; (f) "Dell-T" Assembly for Attaching Two Regulators to a Single Cylinder (Photos by Somers)

Another method of connecting two regulators to a single air source was designed and constructed by James Dell of The University of Michigan. The "Dell-T" (Figure 6-7f) is not available commercially; however, it may be constructed by any competent machinist.

6.2.10 Harness

The SCUBA cylinder is secured to the diver's back with a harness and/or backpack assembly (Figure 6-6). Currently, most single- and double-tank assemblies are fitted with a removable metal or plastic contoured backpack assembly. The waist strap is equipped with a quick-release buckle, and one shoulder strap is generally equipped with release snaps to facilitate donning and permit rapid removal of equipment in an emergency. The backpack must fit the diver comfortably, hold the cylinder securely, and be constructed of corrosive resistant materials. Some backpacks are equipped with a cam-action cylinder release mechanism to facilitate cylinder removal. This mechanism should be adjustable and equipped with a safety mechanism to prevent accidental release of the cylinder. The assembly should be inspected and adjusted, if necessary, *prior to each dive*. For double-tank assemblies, the standard harness (without backpack) is preferred by many divers.

6.3 Preventive Maintenance: SCUBA

Open-circuit SCUBA regulators are durable, but they can be damaged and malfunction unless given reasonable care. Simple preventive maintenance will ensure maximum operating efficiency with minimum repair requirements. SCUBA regulators are built extremely rugged externally but are relatively delicate internally. The clearance between parts is close and foreign material or rust and salt corrosion can cause inefficient operation and malfunction. Observe the following preventive maintenance procedures for open-circuit SCUBA regulators:

- Never stow or transport SCUBA cylinder with the regulator attached.

- Do not allow water or foreign matter to enter the high-pressure inlet of the regulator. *Dry* and insert the protective cap into the yoke to seal the high-pressure inlet immediately after detaching the regulator from the cylinder. When water (salt or fresh) evaporates, it leaves a residue of salts or minerals.

This residue can accumulate on internal parts of the regulator, resulting in friction, decreased functional efficiency, and excessive wear. Chlorinated swimming pool water is nearly as harmful to regulator parts as salt water. Use only plastic or rubber protective caps with a solid core and fitted with an O-ring to ensure a more positive seal. Avoid metal protective caps since electrolysis corrosion may result from the reaction of contact between two different metals and salt water.

Rinse regulator thoroughly with fresh water following each use. The procedure for rinsing single- and double-hose regulators is given below:

Single-hose regulators:

1. With the dust cap in place, flow fresh water, preferably warm, into all parts; a 2-min rinse is recommended to dilute salt water accumulations and remove all foreign matter. This is extremely important for a regulator with the piston-type first stage since salt and sand deposits can interfere with the movement of the piston.

2. Wash the second-stage assembly by flowing water into the mouthpiece and out the exhaust tee. *Do not* depress the purge button while washing the second-stage assembly. This action opens the second-stage valve and will allow salt, foreign matter, and water to enter into the valve assembly, hose, and possibly the first stage. If there is any possibility of the purge button having been depressed during washing, place the regulator on a SCUBA cylinder and allow air to flow through it.

3. Shake excessive water from the regulator and hang it by the yoke to dry.

Double-hose regulators:

1. With protective cap securely in place, wash the regulator housing and exterior of hose with fresh water to remove salt water and foreign matter.

2. Hold the mouthpiece in a vertical position with the exhaust downward. Flow water gently into the mouthpiece to avoid dislodging the rubber intake check valve and admitting water into the intake hose.

3. Remove excess water from the exhaust hose corrugations by blowing through the mouthpiece or shaking the regulator while holding the hose where it clamps to the regulator housing with the mouthpiece up and the hose slightly stretched.

4. Hang by the yoke to dry.

The above procedure is for simple field maintenance of double-hose regulators. It is virtually impossible to keep water from seeping into the intake hose and eventually the air chamber. Periodically the air chamber and intake hose must be cleaned and dried as follows:

(a) Remove hoses from the regulator housing, wash, and hang to dry so the water drains out.

(b) Fill air chamber with fresh water, empty, and shake out excess water. Repeat three times. (Use distilled water if local water has a high alkaline or mineral content.)

(c) Attach regulator to cylinder and position with inlet port pointing downward.

(d) Turn on the air and with a long shanked screwdriver, or similar device, depress the low-pressure diaphragm by inserting the screwdriver through a small exhaust port. This will cause air to flow and dry the inside of the air chamber. Continue air flow for 1-2 min.

(e) Check condition of and properly position exhaust valve.

(f) Reassemble, making certain that hoses are properly positioned with respect to exhaust and inlet ports.

Regulators may be washed by immersing them in a bucket of fresh water. Single-hose regulators may be completely submerged. For two-hose regulators, submerge the housing and hoses but not the mouthpiece. Only partially submerge the mouthpiece with the exhaust side underwater to allow water to enter the exhalation hose.

During storage and transport, protect regulators from abuse, physical damage and exposure to high ozone levels in surrounding air (produces rubber deterioration). A protective container is recommended for carrying regulators in the field.

Careful inspection of the high-pressure inlet filter is an excellent indicator of potential type and source of foreign material that may be entering the regulator. This filter is designed to exclude large particles of foreign material; however, it will not prevent all material from entering the regulator. The following indicators are noted:

- A black, wet substance is an indicator of salt water inside the cylinder.
- A black dust or powder may indicate contamination of the cylinder interior with activated charcoal from the compressor filter.
- A reddish-brown accumulation indicates fresh water inside the cylinder.
- A greenish or turquoise accumulation indicates that salt water has come into contact with the filter and suggests potential internal contamination of the regulator. This is usually a result of carelessness.

6.3.1 Periodic Inspection and Overhaul: Regulators

SCUBA regulators should be inspected by a qualified technician annually. In the event of even minor malfunction, immediate repair is indicated. Annual maintenance procedures involve inspection (and possible replacement) of all rubber parts, pressure-setting adjustments, and evaluation of the internal condition of the regulator. Periodically, the regulator must be completely overhauled, including disassembly, cleaning, and replacement of worn or defective parts. If the regulator has been subjected to abuse and physical shock, it should be inspected by a qualified technician prior to use in open water.

6.3.2 Prevention of Lung Infection

A serious infectious lung condition may result from inhalation of a microorganism (fungus) which contaminates the interior of the SCUBA, particularly double-hose regulator breathing hoses and mouthpiece tees. This fungus growth is more common in tropical areas. The fungus can be eliminated by periodically cleansing the regulator as follows:

(a) disassemble breathing hoses and mouthpiece;

(b) thoroughly scrub the interior of the hoses and mouthpiece components with surgical soap, using a suitable brush;

(c) rinse in fresh water and immerse all rubber parts in a chlorine solution (1/2-cup chlorox to 1-gal water) for at least 2 min;

(d) dry completely and reassemble.

The procedure should be repeated every two weeks during periods of use and prior to storage.

6.3.3 MAINTENANCE OF HIGH-PRESSURE CYLINDERS

Air cylinders and high-pressure manifolds should be rinsed thoroughly with fresh water to remove all traces of salt deposits. The exterior of the cylinder should be inspected for abrasion, dents, corrosion, and rust. If the cylinder has been subjected to severe damage resulting in deep abrasion or denting, it should be hydrostatically tested before refilling. External rust and corrosion should be removed and a protective coating applied to these areas to prevent further deterioration of the cylinder wall. The tank boot should be removed periodically. The portion of the cylinder under the boot is particularly subject to corrosion and rusting since the boot retains moisture next to the cylinder. Occasional application of protective coatings to this area may be required. Also, periodically inspect the area under the tank harness bands for rust and corrosion.

Internal rusting and corrosion are problems that have become more apparent in recent years (Peyser, 1970). Some SCUBA repair facilities claim that approximately 80 percent of all cylinders received for hydrostatic testing have to be tumbled to remove excessive rust from the interior of the cylinder. Care must be taken to prevent moisture accumulations in high-pressure cylinders. When a cylinder is completely drained of air while using a single-hose regulator, water may enter the cylinder through the regulator if the purge button is depressed, allowing the second-stage valve to open. The obvious solution to this problem is never to allow the cylinder to be completely drained of air. Always terminate the dive with a small amount of air remaining in the cylinder (approximately 300 psi is sufficient to keep water from entering the cylinder). *Never* depress the purge button underwater when the cylinder is empty.

Moisture may enter the cylinder during charging. The cylinder should never be completely submerged prior to attachment of the filler assembly. Small amounts of water may be trapped in the valve orifice and injected into the cylinder. Inadequate removal of moisture from air by high-pressure compressor filter systems is another source of internal moisture. Be certain that the compressed air filter system has an adequate moisture separator.

All steel SCUBA cylinders should be internally inspected at least once a year for rust and corrosion. A special rod-type light that illuminates the entire inside of the cylinder should be used for this visual inspection. Most diving equipment suppliers and repair facilities provide this service.

Rust chips may be detected by rocking the cylinder through its horizontal axis while pressing it next to the ear and listening for foreign matter. Also gently tapping an *empty* cylinder with a hammer may reveal internal rust and corrosion. A clean cylinder will have a clear metallic ring and a corroded or structurally weak cylinder gives a dull wooden sound. These procedures are useful when selecting rental or loan cylinders. They are not, however, to be considered as a substitute for visual internal inspections.

If internal inspection reveals rust and corrosion, the cylinder should be cleaned by tumbling. The tumbling process involves filling the cylinder approximately one-half full with an abrasive material such as palet abrasive, carbide chips, or zinc oxide chips and allowing the cylinder to rotate. The abrasive materials remove rust and polish the inside surface of the cylinder. The cylinder is then rinsed to remove loose material and dehydrated internally to remove all traces of moisture.

High-pressure cylinders are subject to Department of Transportation (formerly, Interstate Commerce Commission) regulations. These regulations require that high-pressure cylinders transported from state to state be hydrostatically tested at least once every five years. Most states and cities have ordinances that cover transportation of high-pressure cylinders requiring adherence to Department of Transportation regulations. Diving equipment suppliers and air station personnel will not recharge out-of-date cylinders.

There are several methods of hydrostatic testing of cylinders including direct expansion, pressure recession, pressure and water jacket. The water jacket method is commonly used. In this method the valve is removed and a special test fitting inserted. The cylinder, filled with water, is placed in a water-filled pressure chamber and all air is evacuated. A high-pressure water line is attached to the test fitting and pressure is applied to the inside of the cylinder using a high-pressure hydraulic pump. Before pressure is applied, a burette reading is taken. The burette, attached to the test chamber by a water line, allows the tester to measure the amount of cylinder expansion in terms of water column displacement.

The pressure is increased to one and two-thirds the rated pressure of the cylinder, or in the case of the standard SCUBA cylinder with a rated pressure of 2250 psi, the test pressure is 3750 psi. A second burette reading is taken under full pressure. The water column rises due to expansion of the cylinder. The hydraulic pressure is released and the water column starts to drop, indicating that the cylinder is returning to its original diameter. After all pressure is released, a third burette reading is taken. Based on these burette readings, the permanent expansion of the cylinder is determined. According to DOT regulations, permanent expansion of 10 percent or more of total expansion indicates that the cylinder is unsafe for use. Cylinders that fail hydrostatic testing and show signs of structural damage must be condemned. This can be accomplished by stamping out the DOT (or ICC) specification symbols and figures or boring a hole in the cylinder. A cylinder cannot be restamped for a lower pressure.

The cylinder valve assembly and reserve mechanism should be periodically inspected. Immediate repair is necessary if it is determined that assembly is malfunctioning or faulty. The entire valve assembly should be rinsed with fresh water after diving, and protected from unusual abuse. Frequently, the reserve level is damaged when hit against the roof of a cave or a ship's hull, or when the tank assembly is left unsecured on a boat deck in rough seas. Use a protective shield for cave diving and properly secure tanks at sea and during transport. Cylinders should be tied down, blocked, or otherwise fastened to prevent shifting during transport in vehicles.

When not in use, the valve orifice should be covered with masking tape to prevent loss of rubber O-ring and accumulation of foreign material. Divers should carry extra cylinder valve orifice O-rings attached to the regulator or in the diving equipment bag.

Cylinders containing high-pressure compressed gas can be extremely dangerous if abused or misused. If the pressure of 2250 psi is multiplied by the number of square inches of surface inside a standard cylinder, the force is found to be approximately 433.3 tons. Property damage, physical injury, and even death have resulted from the explosion of high-pressure cylinders. A faulty cylinder is a potential bomb and if a valve is broken off of a cylinder, it is a potential deadly missile.

High-pressure cylinders should be stored in an upright position. Should moisture collect inside the cylinder, corrosion will be less detrimental on the thicker bottom than on the walls. Store cylinders with 100-300 psi pressure to prevent accidentally leaving the valve open and admitting moisture and corrosive agents from the atmosphere. A cylinder which is to be stored for a period of time should not be charged to full pressure. Tests have shown that less internal corrosion occurs at low cylinder pressures. Also, in the event of fire or physical damage, the low pressure constitutes a lesser hazard. Although compressed air normally does not show signs of contamination after storage for long periods, it is advisable to discharge the cylinder and recharge it after one year of storage.

High-pressure cylinders used with open-circuit SCUBA should be filled only with pure compressed air. The rated pressure should not be exceeded by more than 10 percent if over pressure is indicated by a plus (+) following the hydrostatic test date; otherwise, never exceed the pressure stamped on the cylinder. Overfilling places extreme stress on the cylinder walls and may result in metal fatigue. Never allow the cylinder to overheat during charging. Excessive heat, especially involving temperatures above 500^{o} F, can result in significant structural damage.

6.4 Air Compressors and Breathing Media

Air compressors for filling SCUBA cylinders are designed to deliver high-pressure breathing air (Figure 6-8). Compressors for this purpose are available as portable units or for permanent installation. Portable units should have at least 2 cfm output at 3000 lb/in^2 and operate at a low rpm and with a low temperature rise. Larger units for permanent installation should have an output of 8 ft^3/min or more at a pressure of 3000-5000 psi.

Air compressors may be powered by internal combustion engines or electric motors of sufficient capacity, as specified by the compressor manufacturer. Internal combustion engines are a potential source of air contamination, and proper precautions should be taken to ensure that the engine exhaust is prevented from entering the intake of the compressor. Electric motors are recommended for diver air compressors; however, the potential of air contamination is still present and safeguards and precautions are required. A thermal overload cut-off switch is recommended for electric motors.

The compressor must be located in an area where the atmosphere is not contaminated, and proper precautions must be taken to ensure that only uncontaminated air is admitted into the compressor intake. The air entering the compressor must not be exposed to contamination by exhaust from internal combustion sources (compressor engine, ship's engine, generators, etc.) or by contamination from any other source. The air intake must be provided with a suitable dust filter. If necessary, the air intake may be extended out of doors or to a specific source of clean air. If the air intake is extended out of doors, it must be properly protected to prevent entry of excessive amounts of moisture. The extended air intake length should not exceed that recommended by the compressor manufacturer.

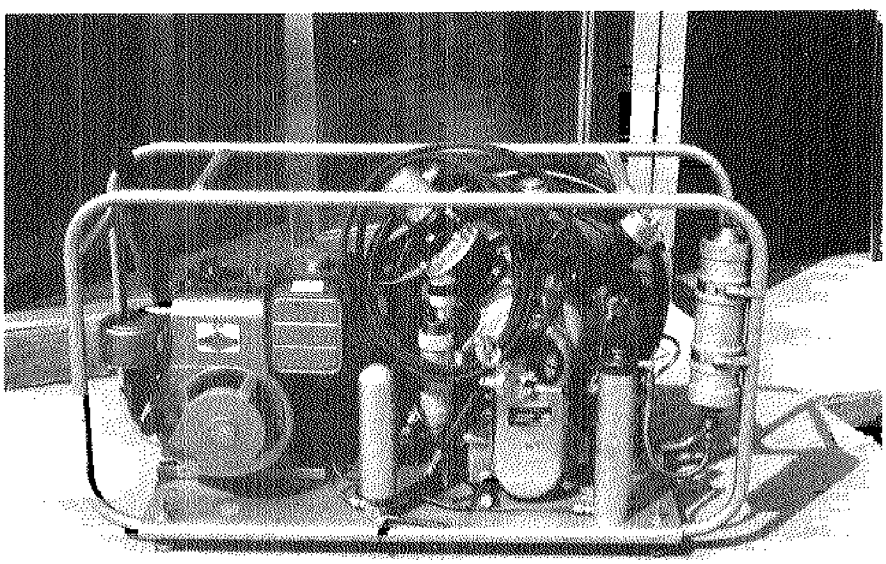


Figure 6-8. Portable High-Pressure Air Compressor for Filling SCUBA Cylinder (Photo by Somers)

Lubricating oils (natural or synthetic) or other lubricants must have the quality and meet the specifications required for compressor service, particularly with regard to flash point, viscosity, and resistance to decomposition and oxidation at elevated temperatures, as specified by the compressor manufacturer. The use of chlorinate lubricants, phosphate ester (pure or in a mixture), or tetrafluoroethylene piston rings must not be permitted. Water-lubricated and dry-lubricated compressors have positive advantages in terms of precluding internal production of carbon monoxide.

Precautions should be taken to prevent overheating of the compressor which may result in formation of oil breakdown products. Methods of cooling high-pressure compressor heads which may be employed include air blowers, water spray systems, or systems incorporated into the compressor. Operations may be cycled to ensure against high temperature rises. A built-in temperature indicator or fail-safe temperature controller may be used if desired.

A filter system must be provided between the compressor and the supply, storage, or diving tanks as a standard part of the compressor equipment. The filter system must be provided with activated carbon, molecular sieve, or other appropriate filters in suitable combination to remove excess water, oil, particulate matter, and odor in order to meet the specified air purity standards. An oil and water (moisture) separator must be provided between the compressor and the filter system. Activated carbon and other filters in the filter system should be examined at least every 24 hr of total compressor operation and a schedule of periodic replacement of filters must be maintained in accordance with the manufacturer's instructions and specifications.

Maintenance and operation of internal combustion and electric motive power and air compressor should be in accordance with the manufacturer's instructions and specifications unless such instructions and specifications would result in infraction of the purity standards for breathable compressed air. Running periods and maintenance operations must be logged. Specific attention must be given to recording of elapsed operating time of the compressor and motive power source, details of maintenance, the type and number of filters used, elapsed operating time of each filter, oil consumption and changes, filter replacements, air analysis, and other pertinent details. A motor-hour meter is recommended to facilitate keeping accurate elapsed operating time records.

Air compressors must be maintained in excellent operating condition and all diving personnel should be trained in the operation and maintenance of compressors. Periodic inspection and factory overhaul are mandatory in accordance with manufacturer's recommendations.

Breathing air must be free from carbon monoxide, carbon dioxide, oil vapor, and other impurities. The air should be periodically analyzed to ensure purity for breathing in accordance with the following specifications:

ELEMENT	PURITY
Oxygen	Atmospheric
Maximum carbon monoxide	0.001% (10 ppm)
Maximum carbon dioxide	0.050% (500 ppm)
Maximum total volatile hydrocarbons	0.001% (10 ppm)
Maximum total oxidants	0.000005% (.05 ppm)
Dust and droplets of water and oil*	Lack of any residue on membrane after passage of 5000 cc of air through filter
Odor	Absent

Table 6-1. Air Purity Specifications

*Maximum moisture content in compressed air for general use is saturated. Compressed air for SCUBA used at temperatures below 20° C is 0.02 mg/liter. Particulates including oil in environments up to 2 atm gauge pressure must not exceed 5 mg/cu m; and above 2 atm must not exceed 1 mg/cu m.

The following air analysis procedures should be used to ensure compliance with the above specifications:

- Compressed atmospheric air at air pollution-free locations will be considered to meet the oxygen and carbon dioxide requirements without testing. However, the content may be determined volumetrically with gas analysis apparatus.

- Methods of analysis for carbon monoxide (laboratory):

    - Standard laboratory method of analysis--iodine pentoxide method.

    - Alternate laboratory method of analysis--infrared spectrophotometry (subject to periodic calibration of test equipment by standard method).

- Method of field analysis for carbon monoxide--NBS colorimetric tubes.

- Oxygen content must be determined by gas chromatograph, standard volumetric gas analyzer, electrometric analyzer, thermal conductivity analyzer, paramagnetic-type analyzer, or color-indicating tube.

- Carbon dioxide content must be determined by gas chromatograph, titrimetric analysis, standard volumetric gas analyzer, or color-indicating tube.

- Liquid water, oil and particulate matter content in a cylinder of air can be determined by supporting a cylinder, valve-down position, for 5 min at room temperature. The valve is then slightly opened and air is allowed to flow lightly into a clean glass container. Condensed water (and oil) may be seen on the glass surface. Other methods to test for water include electrolytic monitor, piezo electric hygrometer, standard dew point apparatus, or electrical conductivity. An alternate oil test is ultraviolet spectroscopy.

- Field tests for visible dust, oil, and water may be made by passing 5000 cc of air through a white-sieve membrane filter. If there is no visible material present on the filter, the air is considered to meet specifications.

- Odors may be determined by sense of smell.

- Total volatile hydrocarbons must be determined with a total hydrocarbon analyzer.

6.5 Air Requirements

The diver must be provided with an adequate supply of pure air. Dive duration is determined by the volume of air contained in the SCUBA cylinders. Air consumption is a function of depth, exertion level, water temperature, and individual physiological variations. The theoretical duration of air supply in a standard SCUBA cylinder at various depths for five levels of exertion is given in Table 6-2.

Air consumption may be calculated for various depths and levels of exertion by using the formula

Depth	Pressure	No-Decompression Limits	Total Duration of Air Supply at Each Depth by Exertion Level 1, 2, 3				
			Very Mild	Mild	Moderate	Heavy	Very Heavy
Ft	Atm	Min	Min	Min	Min	Min	Min
0	1.00	-	113	90	65	51	34
10	1.30	-	87	69	50	39	26
20	1.61	-	70	56	40	32	21
30	1.91	-	60	47	34	27	18
33	2.00	-	56	45	32	25	17
40	2.21	200	51	41	29	24	15
45	2.36	-	48	38	27	21	14
50	2.52	100	45	36	25	20	13
55	2.67	-	42	34	24	19	12
60	2.82	60	40	32	23	18	12
66	3.00	-	37	30	22	17	11
70	3.12	50	36	29	21	16	11
80	3.43	40	33	26	19	15	10
90	3.73	30	30	24	17	13	9
99	4.00	25	28	22	16	12	8
110	4.35	20	27	20	15	11	7
120	4.64	15	24	19	14	11	7
132	5.00	10	22	18	13	10	6
140	5.24	10	21	17	12	9	6
150	5.55	5	20	16	11	9	6
160	5.85	5	19	15	11	8	5
165	6.00	5	19	15	10	8	5
170	6.15	5	18	14	10	8	5
180	6.46	5	17	14	10	7	5
190	6.75	5	17	13	9	7	5
198	7.00	0	16	12	9	7	4

Table 6-2. Theoretical Duration of Air Supply in a Standard, Single, Open-Circuit SCUBA Cylinder at Various Depths for Five Levels of Exertion, with No-Decompression Limits Included for Comparison[4, 5, 6]

Footnotes, Table 6-2

[1]No allowance for time taken in descent or ascent, nor for temperature changes.

[2]All figures are average values for persons in fairly good physical condition; there is considerable individual variation.

[3]To simplify dive planning, these times may be used as "total dive time equivalents"; this allows a minimal air supply safety factor.

[4]Computed with use of a constant; average respiratory minute volume for each level of exertion; very mild, 0.64 ft^3/min; mild, 0.81 ft^3/min; moderate, 1.1 ft^3/min; heavy, 1.4 ft^3/min; very heavy, 2.1 ft^3/min (based on US Navy, 1963; Lanphier and Dwyer, 1954).

[5]Values derived for standard cylinder of 72 ft^3 capacity, charged to 2475 psi (includes + 10 percent); for standard cylinder charged to 1800 psi and US Navy aluminum cylinder charged to 3000 psi, multiply by 0.85 and 1.39, respectively; for twin cylinder SCUBA, multiply by 2.

[6]Modified from Dewey (1962), page 817.

$$\left(\frac{D + 33}{33}\right) C_s = C_d ,$$

where D is depth in feet, C_s is surface equivalent consumption, and C_d is consumption at depth. C_d will vary with water temperature, exertion level, physical condition, etc. The average C_s for moderate exertion levels is 1 ft^3/min. This factor may vary from 0.5 ft^3/min (light exertion in warm water) to 3 ft^3/min or more (heavy exertion in cold water). For example, the cubic-feet-per-minute air requirements for a SCUBA diver doing moderate work at 99 ft may be calculated,

$$\left(\frac{99 + 33}{33}\right) 1 = 4 \text{ ft}^3/\text{min} .$$

However, a diver performing heavy work in cold water at a depth of 132 ft may require 15 ft^3/min,

$$\left(\frac{132 + 33}{33}\right) 3 = 15 \text{ ft}^3/\text{min} .$$

A simplified procedure for rapid calculation of air consumption at depth (C_d) is given by the formula

$$P_a \ (C_s) = C_d ,$$

where P_a is ambient pressure at diving depth in atmospheres (rounded to the nearest 0.5 atm). For example, air consumption under heavy exertion at a depth of 75 ft is found as follows:

$$3.5 \ (2) = 7 \text{ ft}^3/\text{min} .$$

Total dive time on a given volume of air is found by the formula:

$$\frac{V}{C_d} = T_t ,$$

where V is the volume of gas available and T_t is total dive time. Although the diver will likely use less air during the time spent in descent and ascent, calculation of total dive time (T_t), which includes bottom, ascent, and decompression times, provides for a slight safety factor. Moreover, this is the simplest procedure.

Although SCUBA divers are encouraged to remain within "no-decompression" limits, occasionally a decompression dive will be required with SCUBA. Total dive air requirements (C_t) may be calculated using the formula

$$C_d(T_b + T_a) + T_{10} + 1.5T_{20} + 2T_{30} = C_t \ ,$$

where C_d is consumption at depth; T_b is bottom time; T_a is ascent time from bottom to first decompression stop; and T , T_{20}, and T_{30} are decompression times at 10, 20, and 30 ft, respectively. For example, the calculation to determine the total air requirement for a 25-min bottom time, moderate exertion dive to 130 ft is

$$5(25 + 2) + 10 = 145 \text{ ft}^3$$

Assuming that the diver's cylinders contained only 132 ft^3 of air, the diver would have to either

1. shorten bottom time by 3 min (preferable), or

2. provide auxiliary air for decompression (always recommended for a decompression dive, whether one plans to use it or not).

If the diver is working in a situation where it is not possible to provide an auxiliary air supply at decompression stops or he wishes to complete the dive on only the air in his cylinders, the following procedure may be used:

1. Calculate total air requirement for ascent and decompression.

2. Subtract this sum from the total volume of air available in the SCUBA to give the volume available for remainder of dive.

3. Divide the remaining volume by C_d to determine the maximum time allowable before the diver must begin ascent.

For example, determine the maximum bottom time for a 130-ft dive assuming a volume of 132 ft^3 air in the cylinders. Using the formula,

$$C_d(T_a) + T_{10} + 1.5T_{20} + 2T_{30} = C_a \ ,$$

where C_a is total air consumption during ascent and decompression. Then

$$5(2) + 10 = 20 \text{ ft}^3$$

and

$$132 - 20 = 112 \text{ ft}^3.$$

Therefore,

$$\frac{112}{5} = 22 \text{ min allowable bottom time (approximately).}$$

Another excellent method of determining when the diver must start ascent based on air requirements for ascent and decompression is by SCUBA pressure readout. For example, in the previous example a total of 20 ft^3 of air was required for ascent and decompression. To calculate the minimum readout pressure that would still allow the diver sufficient air to ascend, use the formula:

$$\frac{C_d(T_a) + T_{10} + 1.5T_{20} + 2T_{30}}{k} = P_r ,$$

where k is the constant for a given SCUBA cylinder and P_r is the pressure gauge readout. Using the previous dive example,

$$\frac{5(2) + 10}{.03} = 700 \text{ lb/in}^2 \text{ (approximately).}$$

Therefore, the diver using a double-cylinder SCUBA (71.2 ft cylinders) must terminate at a minimum readout pressure of 350 lb/in^2 since this is 350 lb/in^2 in each cylinder.

6.6 Calculation of Air Volume at Various Cylinder Pressures

Occasionally self-contained divers are required to dive with partially filled SCUBA cylinders. For proper dive planning, the exact volume of air available may be determined using the formula

$$\frac{P_g}{P_r}(V_r) = V ,$$

where P_g is cylinder gauge pressure, P_r is the rated pressure, V_r is rated cylinder volume, and V is the volume of *free* air in the cylinder. For multiple cylinder units, multiply V by the number of cylinders. For example, the volume of free air contained in a standard 71.2 ft^3 cylinder at a gauge pressure of 1600 lb/in^2 is

$$\frac{1600}{2475}(71.2) = 45.6 \text{ ft}^3 .$$

To simplify the calculation of remaining volume, a "constant" may be used as follows:

$$P_g(k) = V ,$$

where the constant (k) is V_r/P_r. The following are constants for SCUBA cylinders currently used:

Rated Volume (V_r)	Stamped Pressure	Rated Pressure (P_r)	Constant (k)
71.2	2250	2475	.0288
52.8	1800	1980	.0267
50.0	2250	2475	.0202
42.0	1880	2068	.0203
38.0	1800	1980	.0192

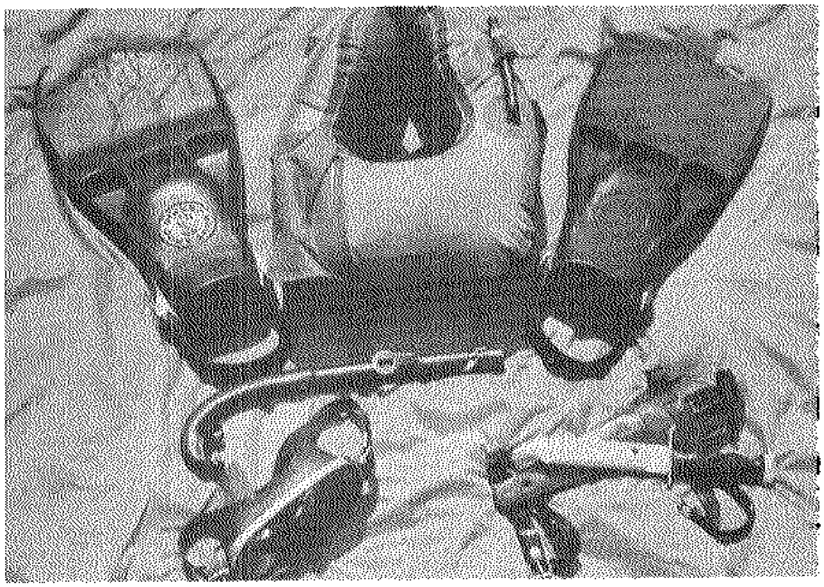
Approximate values, generally adequate for most SCUBA diving calculations, may be determined by using k rounded to the nearest .01, i.e., .0288 = .03.

6.7 Accessory Equipment

See Figure 6-9a, b.

6.7.1 Face Mask

The face mask (Figure 6-9b) provides increased clarity and visibility underwater by placing an air space between the eyes and the water. There are two general classes of face masks: the separate face mask and full-face mask. The separate face mask, covering only the eyes and nose, is normally used for diving with SCUBA equipped with a mouthpiece or for skin diving. Full-face masks are used with specific SCUBA and surface- or tether-supplied apparatus. These systems will be discussed later.



a

b

Figure 6-9. Accessory Equipment for Skin and SCUBA Diving: (a) Basic Skin Diving Outfit; (b) Masks (Photos by Somers)

The face mask consists of a faceplate, a frame (face blank or body), and a headstrap. Faceplates of shatterproof, clear glass are recommended. Plastic faceplates are subject to discoloration, abrasive damage, and considerable fogging during dives. The frame is a flexible rubber carrier designed to hold the faceplate and provide a watertight seal. The major portion of the frame should be of sufficient rigidity to hold the rubber plate away from the nose. The rubber edge should be soft and pliable enough to ensure perfect fit to the contour of the face and comfort; however, it must be sufficiently rigid to retain its shape. This edge may be fashioned of tapered neoprene rubber or thick foamed-neoprene rubber. A noncorrosive, adjustable, metal retainer band is required to secure the faceplate in the frame. An adjustable rubber headstrap holds the mask to the diver's head. This strap should be approximately 1 in. wide and/or split at the rear of the head for better security and comfort. The headstrap should be secured to the metal retainer band or frame by metal strap anchors which facilitate adjustments and prevent slippage of the strap.

A mask may be equipped with a nose-blocking device to facilitate equalization of pressure during descent. Three basic types of nose-blocking devices are: (1) a foamed-neoprene rubber pad positioned below the nostrils for sealing off the nostrils by pushing upward on the mask, (2) finger pockets in the mask frame on each side of the nose to facilitate pinching the nostrils shut with the fingers, and (3) a formed nose pocket to facilitate pinching the nostrils. The rubber pad is recommended for use when diving with neoprene mittens and the nose pocket is desirable for divers who have difficulty equalizing or for skin divers.

A mask may also be equipped with a purge valve, a device to facilitate clearing water from the mask. This purge device consists of a thin, circular, neoprene rubber, check valve, generally protected by a vented plastic cover and housing. Underwater, this one-way check valve is held flush against its housing by increased water pressure. Exhalation through the nose forces water through the valve from inside the mask. Caution must be taken when selecting masks equipped with purge valves since many are subject to failure and leakage. Only high-quality masks with large check valves are recommended.

Face-mask selection is a matter of individual preference, fit, comfort, and diver requirements. Masks are available in a variety of sizes and shapes, ranging from larger, wrap-around models with side lenses for greater peripheral vision to small, lightweight, compact models with minimal internal volume.

Avoid plastic construction, extremely large-size mask, built-in snorkels, narrow headstraps, and goggles. Purge valves and nose-blocking devices are optional.

Those individuals who need to wear eyeglasses generally require some form of optical correction underwater. Large-size prescription lenses can be permanently bonded to most faceplates with optically clear epoxy by an optician specializing in underwater vision problems. Williamson (1969) discusses vision problems and corrective measures in detail.

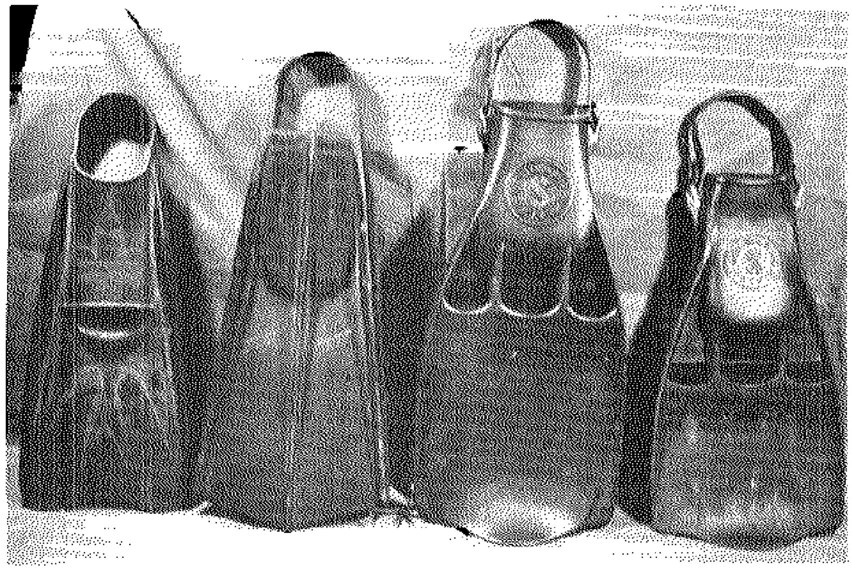
The mask should fit comfortably and form an airtight seal on the face. To test for proper fit, the mask is placed in position without securing the headstrap. The mask is properly sealed if and when the diver inhales through the nose, it will remain in place without being held.

Ventilation across the faceplate is generally poor in any mask and the glass tends to fog easily. To minimize fogging, thoroughly smear the inside of the faceplate with saliva and rinse lightly prior to donning. Antifogging solutions such as mild liquid soap or a special commercial preparation may be applied to the inside of the faceplate. The faceplate should be frequently washed in detergent to remove oils and film that enhance fogging. If the mask fogs during use, admit a small amount of water into the mask and roll it across the fogged areas.

6.7.2 Swim Fins

Swim fins (Figure 6-10a) increase the propulsive force transmitted from the legs to the water. Used properly, the swim fins conserve the diver's energy and facilitate all underwater movements. Swim fins are available in a variety of sizes and designs. Variations in characteristics include size and shape of foot pocket; size, shape, angle, and degree of stiffness of blade. Selection of fins is a matter of individual preference, mission requirements, fit, and physical condition. Performance is dependent upon fin design, the style of diver's kick, and the force in which this style is applied to the water.

In general terms there are two styles of fins: swimming and power. Swimming-style fins are smaller; lighter weight; and slightly more flexible than the power style; and used with a wider, more rapid kick of less thrust. The blade may have a greater angle. Some utilize an open vent or overlapping blade principle which gives the swimmer maximum thrust with minimum energy requirements. This style uses approximately as much force on the up-kick as on the downward kick. The swimming-style fin is less fatiguing for



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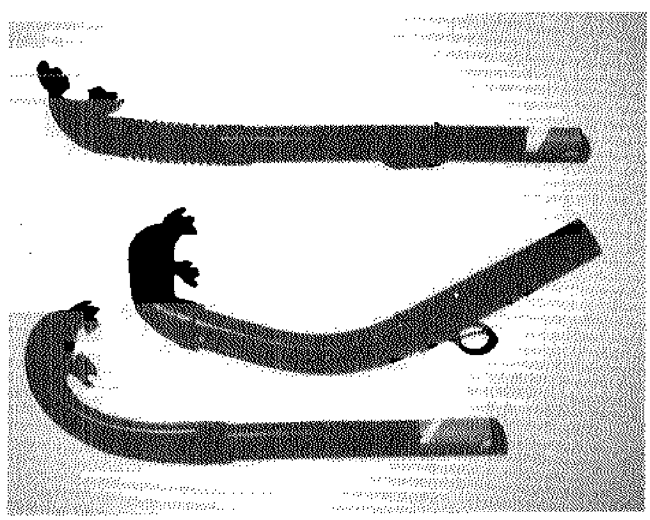

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Figure 6-10. Accessory Equipment for Skin and SCUBA Diving: (a) Swim Fins (Left to Right): Shoe, Heavy-Duty Open-Heel, Heavy-Duty Adjustable, and Standard Adjustable; (b) Snorkels (Photos by Somers) extensive surface swimming, less demanding on leg muscles, and more comfortable. This type of fin is recommended for trainees. Power-style fins are longer, heavier, and more rigid than swimming fins. They are used with a slower, shorter kicking stroke with emphasis on the down kick. This style fin is designed for maximum power thrust of short duration with a sacrifice in comparative comfort, and is desirable for working divers who are required to swim while encumbered with multiple-cylinder SCUBA and heavy equipment. Many divers own both swimming-style and power-style fins. Buoyant and nonbuoyant models are available in both styles; this factor doesn't generally affect the quality or performance of the fin.

Swim fins are available in open- or enclosed-heel models. Open-heel models are recommended for use with coral shoes or rubber boots. They are much easier to don and fit more comfortably. The open-heel models have either an adjustable strap or a one-piece nonadjustable strap. Adjustable strap models are designed to accommodate a wide range of foot sizes; however, they are less comfortable when worn without foot protection.

The strap buckle must be sturdy and designed to hold the strap securely in place. Since open-heel fins have a closed toe section, the fin must be properly sized to prevent cramping of the toes. Open-heel fins are generally larger and stiffer than closed-heel models. Closed-heel fins are often used for diving in warmer climates where exposure suits and boots are not required. Even in warmer waters some divers prefer some sort of foot protection (socks or boots) to prevent chafing and blisters, especially if they wear fins for long periods of time.

Basically, the fin must fit comfortably. It must be properly sized to prevent cramping or chafing. Furthermore, the fin must match the individual's physical condition.

6.7.3 SNORKEL

The snorkel (Figure 6-10b) is a J- or L-shaped rubber or high-impact plastic tube which enables the diver to breathe while swimming on the surface, without moving his head. For efficient and easy breathing, the tube diameter should be 5/8 in. or larger and not exceed 15 in. in length. The mouthpiece should be pliable and nonrestrictive with a cross-section that is approximately equal to that of the tube. Snorkels with valve mechanisms are *not* recommended. Contoured, large-tube snorkels are popular for skin divers. These offer minimal resistance to breathing and swimming.

Most self-contained divers carry a snorkel to facilitate surface swimming when the SCUBA air is depleted. Many divers carry the snorkel attached to the mask strap while SCUBA diving; however, the diver should be careful to prevent accidental dislodging of the mask. A "flexible" lower tube is advisable if the snorkel is attached to the SCUBA diver's mask. The snorkel may be more safely carried on a lanyard or under the knife strap.

6.7.4 LIFEJACKET

A carbon dioxide or air-inflatable yoke-type lifejacket (Figure 6-11) is mandatory for self-contained divers. It is one of the diver's best safeguards against drowning, especially in rough seas or when highly fatigued. However, it is not and must not be used as a substitute for swimming ability and physical fitness. The lifejacket must be designed so it can be inflated by manual activation of the gas cylinder or an oral tube. The only acceptable lifejacket is the "yoke" type, which holds the diver's head clear of the water when inflated even if the diver is unconscious. Lifejackets should be lightweight, relatively compact, rugged, comfortable, and provide maximum flotation. Neoprene-impregnated nylon is a desirable fabric. The UDT-type lifejacket (Figure 6-11a) is recommended for surface swimming and self-contained diving. This jacket is fitted with a 19-g CO_2 cylinder and is capable of lifting approximately 19 lb from 18 ft. The harness arrangement on this lifejacket has proven most satisfactory. Some vests are fitted with multiple CO_2 cylinders, pressure relief valves, and oral tubes located at the back of the neck.

The compressed-air lifejacket (Figure 6-11b) is similar in design and construction materials; however, it is considerably more bulky and has a greater capacity and buoyancy. A compressed-air cylinder, refillable from a standard SCUBA cylinder, provides gas for manual inflation. This vest is fitted with pressure relief valves to facilitate purging excess gas during free ascent. A flexible tube is fitted to the vest at the back of the neck. With proper training and practice, the diver could use this tube (equipped with a mouthpiece and special valve mechanism) for breathing during an emergency ascent. A compressed-air lifejacket should not be used by an inexperienced diver. Its capacity for rapid inflation and ascent demands respect and careful handling. For a detailed discussion of compressed-air vest, see Tzimoulis (1971, 1972) and McKenney (1968).

Lifejackets are frequently used as "buoyancy compensators" to compensate for improper weighting of the diver and wet-suit

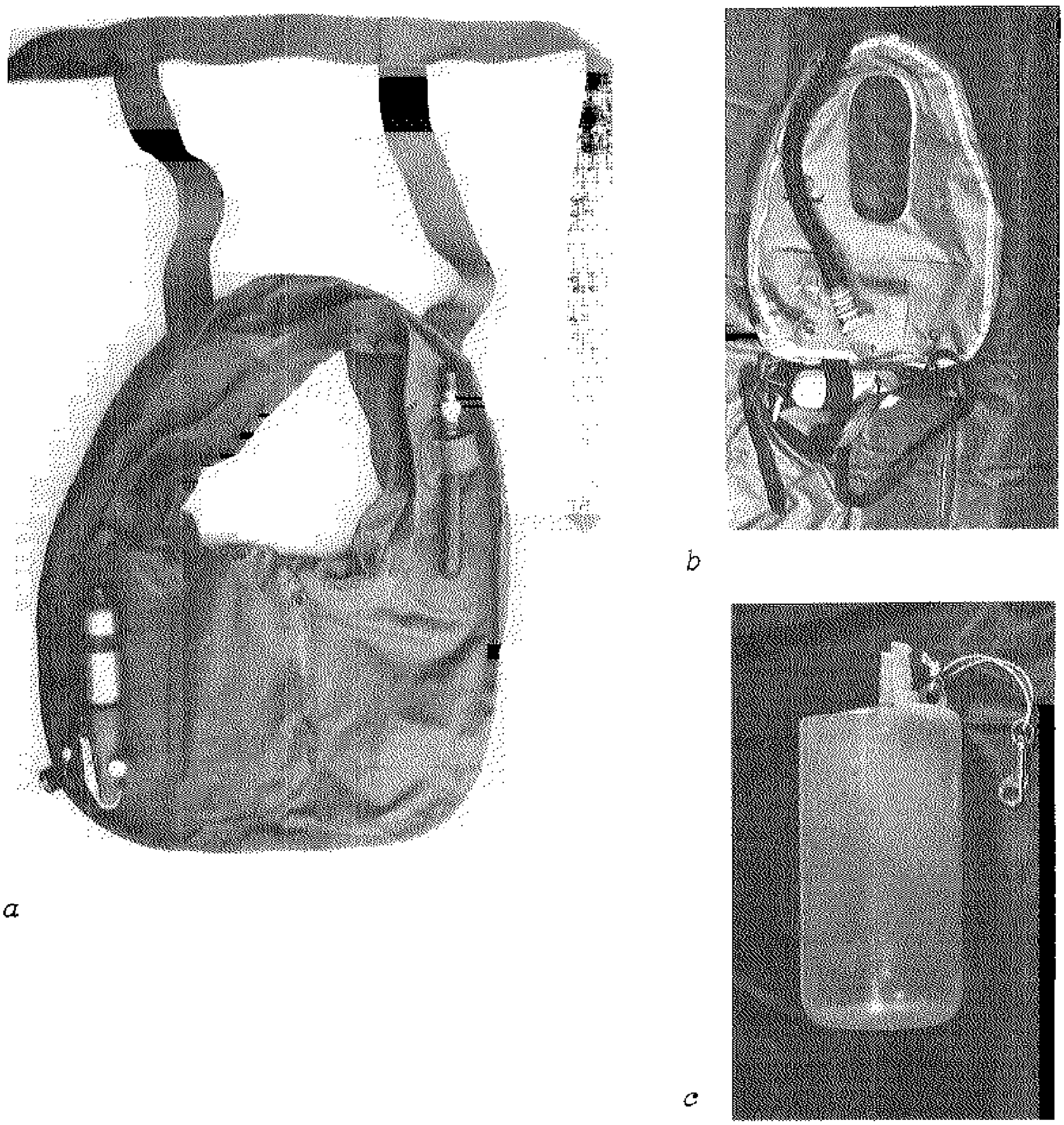

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Figure 6-11. Lifejackets and Buoyancy Compensators: (a) Standard Yoke-Type, CO_2 Inflatable Lifejacket (UDT Type) Designed for US Navy Underwater Swimmers; (b) Yoke-Type, Compressed-Air Inflatable Lifejacket; (c) Plastic Gallon Container with Snap Hook for Buoyancy Compensation (Photos by Somers) compression at depth. Care must be taken to prevent overinflation and subsequent loss of control during ascent. Also, oral inflation and deflation procedures must be mastered under controlled conditions prior to use in deep water. The compressed-air vest is desirable since buoyancy compensation can be accomplished by a burst of air from the cylinder rather than orally. Never use a lifejacket to compensate for extreme overweighting; remove weights from the belt. The lifejacket should only be used to compensate for a few pounds of excess weight. Some divers also use a small plastic container for buoyancy compensation. A gallon container (Figure 6-11c) will provide approximately 9 lb buoyancy. The container is carried in the diver's hand or snapped to the cylinder harness in a convenient location.

Since the lifejacket is essentially a piece of lifesaving equipment, it should be maintained accordingly. Rinse and inspect the lifejacket after each dive. Periodically inspect and lubricate activator mechanism. The gas cylinder should be checked prior to each dive and the cylinder threads lubricated. Periodic activation and inflation tests are recommended. The need for preventive maintenance is increased when vests are used as "buoyancy compensators." Water must be drained from the lifejacket following each dive and the inside rinsed, activation tests must be performed more frequently. Periodically inflate the lifejacket and check for leaks by immersing it in water. Small holes may be repaired using an appropriate cement and pieces of similar material. Lifejacket maintenance procedures are further discussed by Church (1970).

The procedure for dissassembly, inspection, and reassembly of the UDT-type lifejacket used at The University of Michigan is as follows:

1. Remove CO_2 bottle from the CO_2 inflation assembly.
2. Remove CO_2 inflation assembly securing nut with 9/16 box wrench.
3. Remove rubber washer with scribe, taking care not to tear it if possible.
4. Remove CO_2 inflation assembly from inflation chuck.

5. Using a drift punch, remove drift pin on which operation handle pivots. (Caution: Pin will only come out one way; use drift on small end of pin.)

6. Remove the operation handle from the assembly.

7. Remove the firing pin and spring from the channel in the inflation assembly, using a special punch.

8. Inspect for corrosion, clogging, wear, and broken parts.

9. Inflate lifejacket by means of oral inflation tube and water check for air leaks as follows:

   a. The lifejacket must be *clean* and *dry*. If necessary, use a chemical cleaner such as Toluol; apply two to three coats with a brush. Do not attempt to smooth chemical film after drying has started.

   b. Apply one coat of cement to neoprene (smooth) side of patch. Let dry and apply a second coat.

   c. Let the second coat of cement partially dry until it becomes tacky, and then place a patch over puncture. Squeeze or roll out any air bubbles that may be present.

   d. Apply pressure to patch by placing a weighted object on top.

   e. Twenty-four hours minimum is recommended for patch curing at no less than 70° F. Complete curing will require two to three days. It is recommended not to apply full pressure to the vest before that time elapses.

10. Carefully clean all parts of CO_2 inflation assembly with steel wool or a wire brush, using a solvent if necessary.

11. Wire-brush the threads of inflation chuck on jacket.

12. Wire-brush the threads of CO_2 cylinder (hand brush only; do not put on a powered-wheel brush).

13. Lubricate the following parts with waterproof silicone grease:

    a. firing pin,

    b. firing pin channel,

    c. operating handle,

    d. operating handle slot,

    e. base and threads of inflation chuck,

    f. CO_2 cylinder threads,

    g. threads in top of CO_2 inflation assembly.

14. Replace firing pin and spring in firing pin channel.

15. Replace operating handle, taking care to have the arm of operating handle on correct side of inflation assembly.

16. Replace drift pin connecting operating handle to inflation assembly, taking care to insert pin properly.

17. Check operation of firing pin and spring, by working operating handle. If pin or spring is faulty, replace with new part.

18. Replace inflation assembly on inflation chuck.

19. Replace rubber washer.

20. Replace assembly securing nut and tighten snugly with 9/16 box wrench.

21. Insert specially adapted CO_2 bottle in the inflation assembly and inflate lifejacket with compressed air to test inflation device CO_2 passages. (A CO_2 cylinder may be used if special inflation assembly is unavailable.)

6.7.5 Knife

The diver's knife (Figure 6-12a) is his safeguard against entanglement

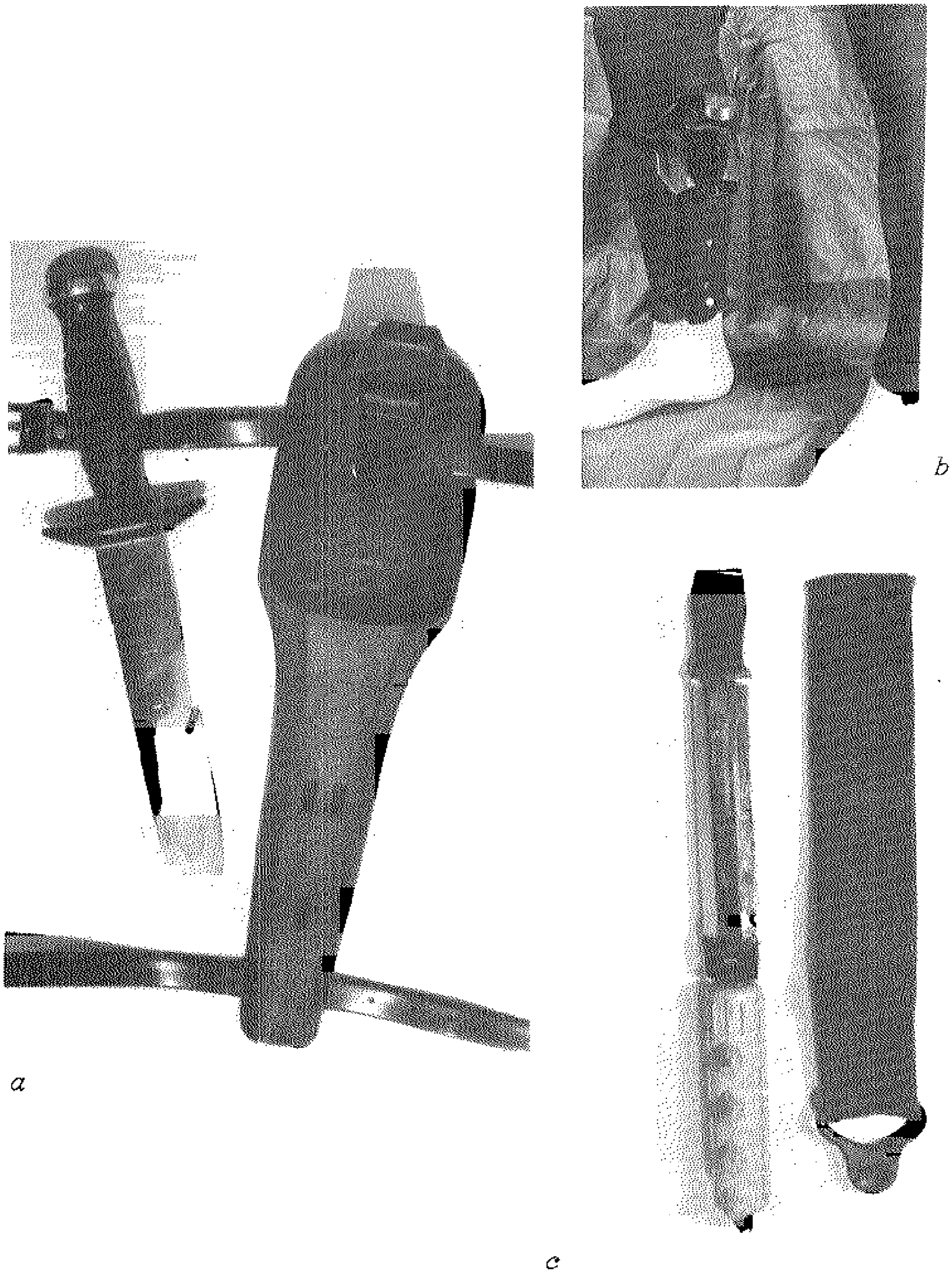


Figure 6-12. Diver's Knife and Tool: (a) Standard Knife and Leg Scabbard; (b) Diver Wearing Knife on Inside of Leg to Minimize Snagging; (c) Combination Knife and Pry Bar (Photos by Somers)

and serves as a valuable tool. It should be made of high-quality, noncorrosive metal. The blade is 5-7 in. long and approximately 1 in. wide. One side is a sharp edge and the other is serrated. The serrated edge is particularly useful for cutting water-soaked fiber lines and even lightweight cable. A large, contoured handle with a metal protector at the base is desirable. The knife is generally carried in a plastic scabbard attached to the diver's belt or leg. Placing the knife on the inside of the leg (Figure 6-12b) lessens the possibility of snagging it on line or plant growth.

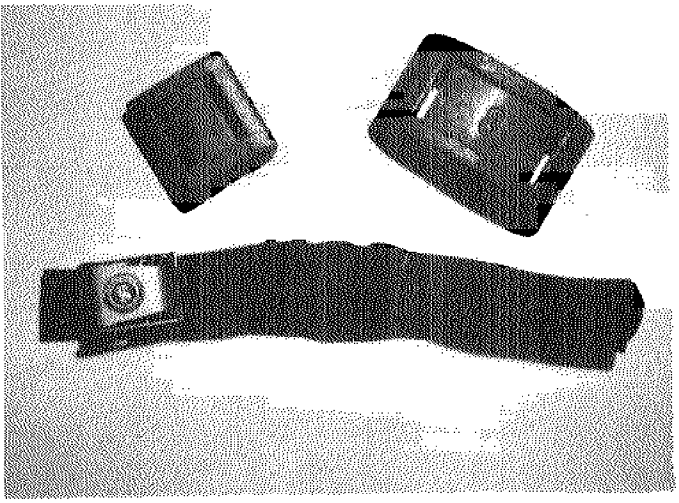
A "diver's tool" (Figure 6-12c), which is a combination knife and pry bar, is very useful in scientific work. Diver's knives and tools should be washed in fresh water after the dive and metal parts treated with a light coating of oil or silicone.

6.7.6 WEIGHT BELT

A weight belt (Figure 6-13a) is frequently required to offset natural buoyancy or the buoyancy of a diving suit. Buoyancy factors will be discussed later. The belt is generally constructed of 2-in. nylon webbing with a quick release buckle. A "positive-release" buckle (Figure 6-13b) is recommended since once it is released, it cannot close again. The "positive-tension" type has special applications, e.g., cave diving. Molded-lead weights are attached to the belt. Weights are available in 1- to 10-lb sizes, although 2-, 3-, and 5-lb sizes are used most frequently. Contoured hip weights (Figure 6-13a) are more comfortable; however, they limit weight adjustments. Always wear the weight belt over all other equipment so it can be readily released without obstruction.

6.7.7 WATCH

A watch (Figure 6-14) is essential to the SCUBA diver for determining bottom time, controlling rate of ascent, and navigation timing. It is mandatory for dives below 50 ft. The diver's watch must be pressureproof and waterproof; a screw-type sealing crown is recommended. It should have a heavily constructed case, be highly shock resistant, self-winding, and nonmagnetic. A black or orange face with large, luminous hands and dial is necessary for utmost visibility in deep water. An external, self-locking bezel is required for registering elapsed time. A heavy-duty band of plastic, rubber, or metal is desirable.



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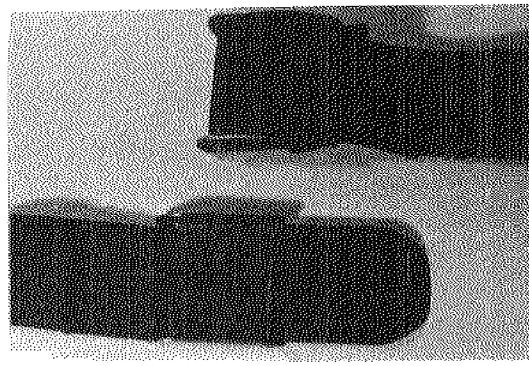

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Figure 6-13. Weight Belts for Skin and SCUBA Divers: (a) Weight Belt with Expandable Section to Compensate for Wet-Suit Compression, 3-lb Weight, and 8-lb, Contoured Hip Weight; (b) Quick-Release Buckle (Below) and Spring-Loaded Positive-Release Buckle (Above) (Photos by Somers)

Many inexpensive diver's watches are available; however, experience has shown that these watches have a tendency to leak and will not sustain repeated, rugged use. An example of a satisfactory diver's watch is the Rolex Submariner distributed by the American Rolex Company. These watches are expensive but they have proven themselves through years of satisfactory service. A heavy-duty, inexpensive metal case is available for use with inexpensive watches (Figure 6-15a). This case has proven satisfactory to depths in excess of 200 ft. Since the case is not equipped with a bezel, the diver must set both hands on 12 or record descent time on a small slate. *Do not rely on memory!*

All diver's watches should be washed in fresh water after use in salt water and serviced regularly in accordance with manufacturer's recommendations.

6.7.8 Depth Indicator

Self-contained divers must continuously monitor their depth for decompression and air consumption purposes. If the depth is constant and the diver is working in a limited area, a sounding line or fathometer will give indication of depth. Generally, self-contained divers move around the area, and the depths at

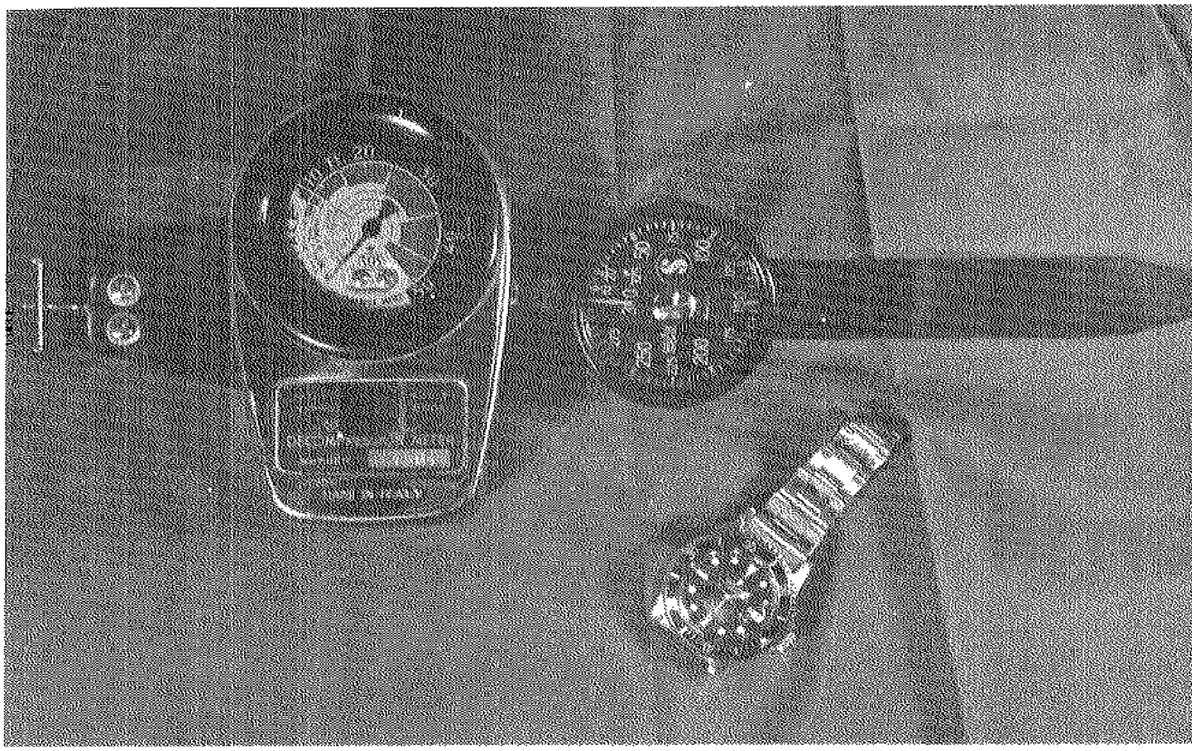
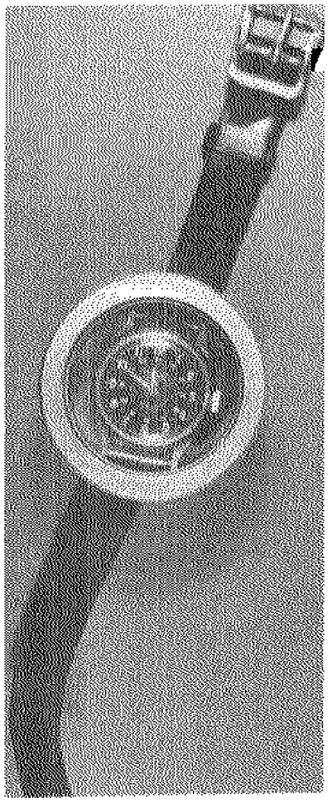


Figure 6-14. Accessory Equipment for Skin and SCUBA Divers: Decompression Meter, Depth Indicator, and Underwater Watch (Photo by Somers)

which they work may vary considerably during a single submergence. This necessitates the use of a self-contained depth indicator (Figure 6-15b, c).

Depth indicators available at present are generally of the open or sealed Bourdon tube, diaphragm, or capillary type. The open Bourdon tube depth indicator consists of a spiral-shaped metallic tube with one open end. This tube is contained in a metal case with the open end exposed to the external water. The closed end is connected, by linkage, to a pointer which rotates around a calibrated dial. The water enters the open end of the tube and pressurizes the bore. The differential between the bore and the sealed case causes the tube to deflect from the original shape; this movement is transmitted to the pointer. The sealed Bourdon tube depth indicator is completely enclosed in oil-filled, neoprene-metal and neoprene housing (Figure 6-14). The water pressure



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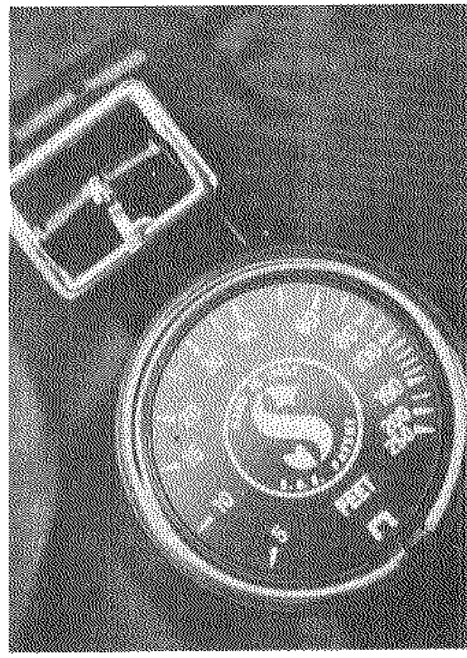

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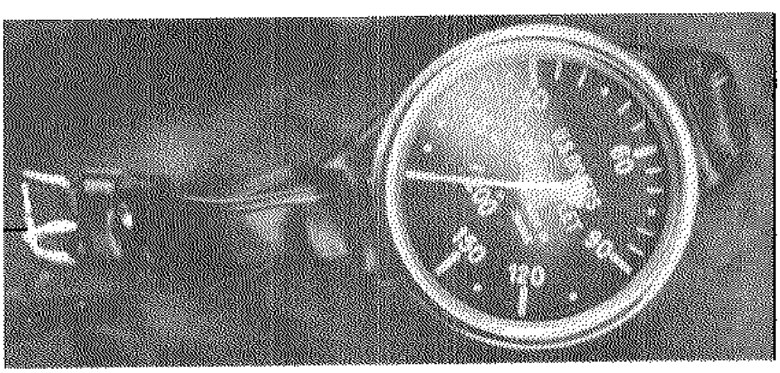

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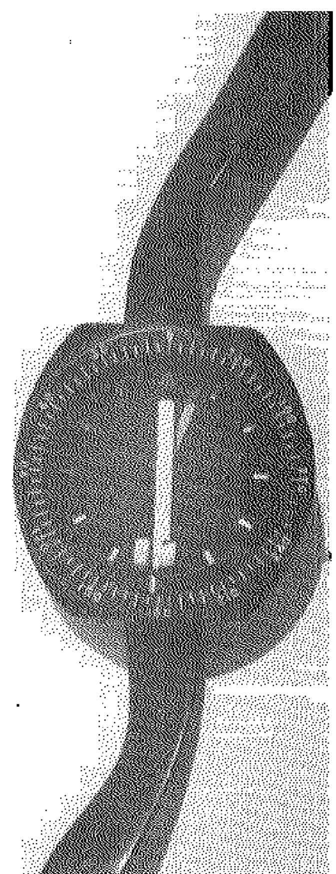

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Figure 6-15. Accessory Equipment for Skin and SCUBA Divers: (a) Watch in Heavy-Duty, Waterproof Case; (b) Capillary-Type Depth Indicator; (c) Diaphragm-Controlled Mechanism Depth Indicator; (d) Underwater Compass (Photos by Somers) acts upon the housing, which is flexible and functions as a diaphragm. This allows the sealed Bourdon tube to be subjected to the ambient pressure. This type of gauge is subject to error because of temperature change, permanent set of the tube induced by impact or shock, and corrosion of the tube. With proper care and adequate maintenance, these gauges will operate satisfactorily.

The diaphragm-controlled mechanism gauge (Figure 6-15c) is basically composed of a pocket of dry air, separated from the surrounding medium by a metal membrane. The pressure differential between the air pocket and surrounding medium moves the metal membrane, which by linkage moves the pointer. This type is reasonably shock resistant and is not affected by internal corrosion as the open Bourdon tube type. However, it is subject to temperature variation.

The capillary-type depth indicator (Figure 6-15b) consists of a tube closed at one end and secured to a calibrated dial. As the diver descends, ambient pressure forces water into the tube, thus compressing the entrapped air. The water level indicates the depth. This type of depth indicator is inexpensive and relatively accurate in shallow water (to 60 ft). The diver is cautioned against jump-type entries which may force air and water into the tube with a subsequent broken water column and false readings.

The depth indicator is generally secured to the wrist of the diver by a heavy plastic or neoprene strap. The case should be of heavy metal or neoprene with a thick Plexiglas port. A large dial is desirable with the numbers, calibrations, and needle coated with radium paint to permit ease of reading in dark water. The gauge should be calibrated from 0 to 200 ft (or deeper, depending on mission requirements). Depth gauges are generally calibrated for salt water. When using them in fresh water, multiply the reading by 1.025.

After use, particularly in salt water, depth indicators should be rinsed in fresh water. The depth indicator should be protected from physical abuse; stow and transport in separate padded container. All depth indicators should be periodically calibrated by checking against a measured line or pressurizing in a chamber.

6.7.9 Safety Line and Reel

A safety or lifeline (Figure 6-16) is the cave diver's only dependable link with the surface. In addition, a line and reel are useful in search and recovery work and as a distance line on decompression dives.

The line reel should be of simple design, lightweight, foulproof, rugged, easy to handle, and dependable. The line should reel off smoothly and effortlessly without backlash. Thus, when the diver stops pulling off line, the reel stops. The diver should be able to rewind the line with a minimum of effort and no fouling. Until recently, nearly all diving reels or "line retainers" (see Figure 6-16 and also Figure 6-18b) were in individual design and construction. Now a satisfactory safety line reel (Safline Reel) is manufactured by the Ideal Reel Company of Paducah, Kentucky. A detailed description and evaluation of the reel has been published by Tzimoulis (1968).

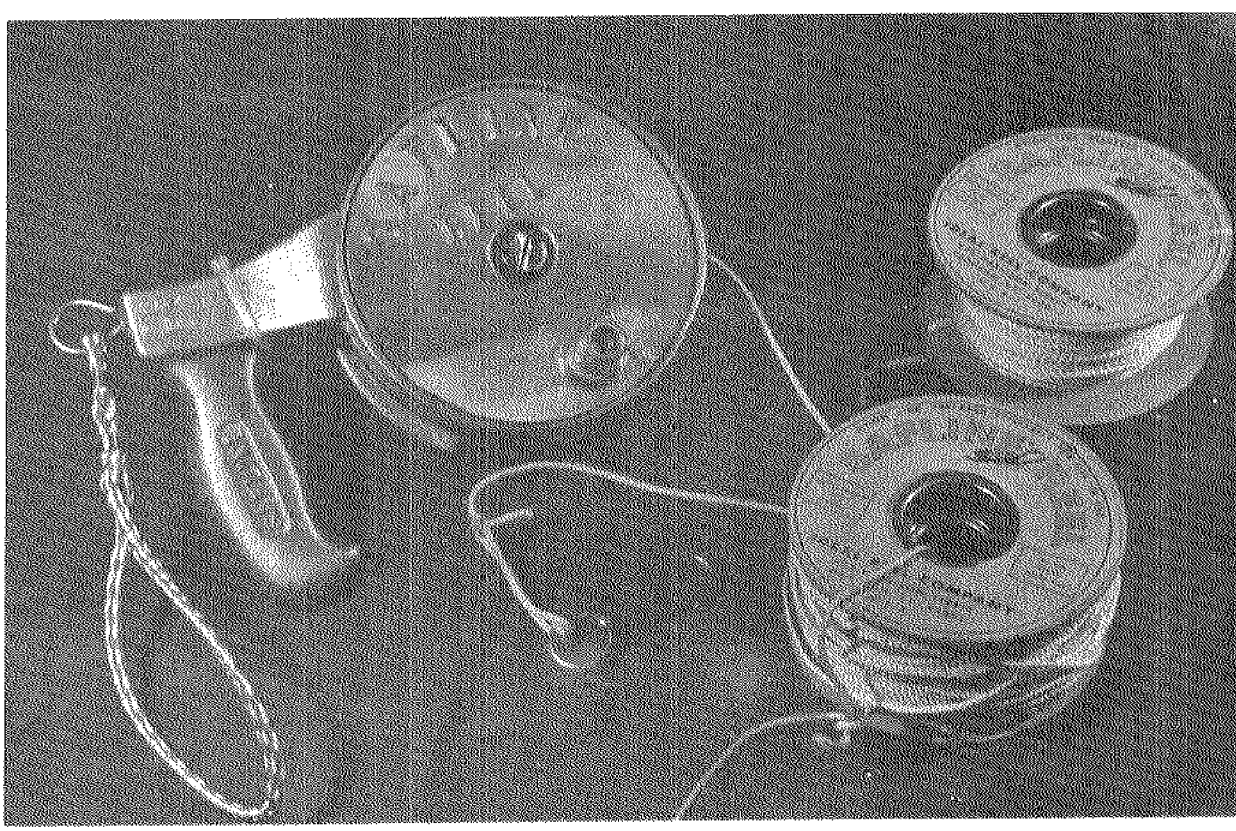

Figure 6-16. Safety Line and Reel (Photo by Somers)

The Safline reel accommodates 100 ft of 1100 lb test, 200 ft of 525 lb test, or 400 ft of 315 lb test braided nylon line. Nylon is the first choice for diving safety lines due to its high strength versus size ratio and resistance to rotting. A line of 525 lb test is considered as minimum and 1100 lb test is used for adverse conditions. The increased diameter is easier to handle as well as stronger. To traverse long distances, each diver can take a reel and simply use several reels in series. The junction between these lines must be secure. Some cave divers do prefer to use a lighter line contained on one reel. One cave diving group requested 1200 ft of 160 lb test line on a single reel (Ideal Reel Company, personal communication); the use of extremely light line is not recommended.

Reels and lines should be inspected prior to each dive. After a dive, unreel the safety line to dry and inspect for damage. If the line shows signs of damage or weakness, it should be replaced.

6.7.10 Underwater Lights

An underwater light (Figure 6-17) is necessary for cave diving, night diving, and working around submerged objects where sunlight is cut off. Do not expect a light to aid in murky or dirty water. In fact, under these conditions a light will give an undesirable effect due to reflection on suspended particles, much the same as auto headlights in a fog.

Early model hand lights were frequently inadequate in candlepower, sealing method, resistance to pressure, and dependability. Now there are several underwater lights available that are brilliant, strong, and reliable. Most major diving equipment manufacturers or distributors offer one or more models. Basically, most underwater lights are constructed of a durable plastic case with a pistol-grip handle, plastic headpiece, removable O-ring between the case and sealed beam lamp, switch, and internal wiring system. A 6-volt spring or screw terminal lantern battery powers the seal beam lamp producing about 40,000 candlepower. A few brass or aluminum case models are available, and some are powered by standard "D" or nickel cadmium batteries. Lentz (1967) summarizes standard diving lights and their construction.

A highly satisfactory underwater light is the Dive Bright 500 B (Figure 6-17a) by the Allen Engineering Company of Belmont, California. This light features an extremely durable aluminum case, anodized, and painted with epoxy paint, and a 1/2-in. O-ring-sealed, optical-grade Plexiglas lens. The light utilizes ten standard size "D" or nickel cadmium batteries to deliver more than 80,000 candlepower. A hermetically sealed internal reed switch is operated with a permanent magnet affixed to the exterior of the case; there are no case penetrations. The light weighs 1 lb in water. All components are easily replaced if repairs are necessary. Excellent, moderately priced, rechargeable, nickel-cadmium-powered lights are also available.

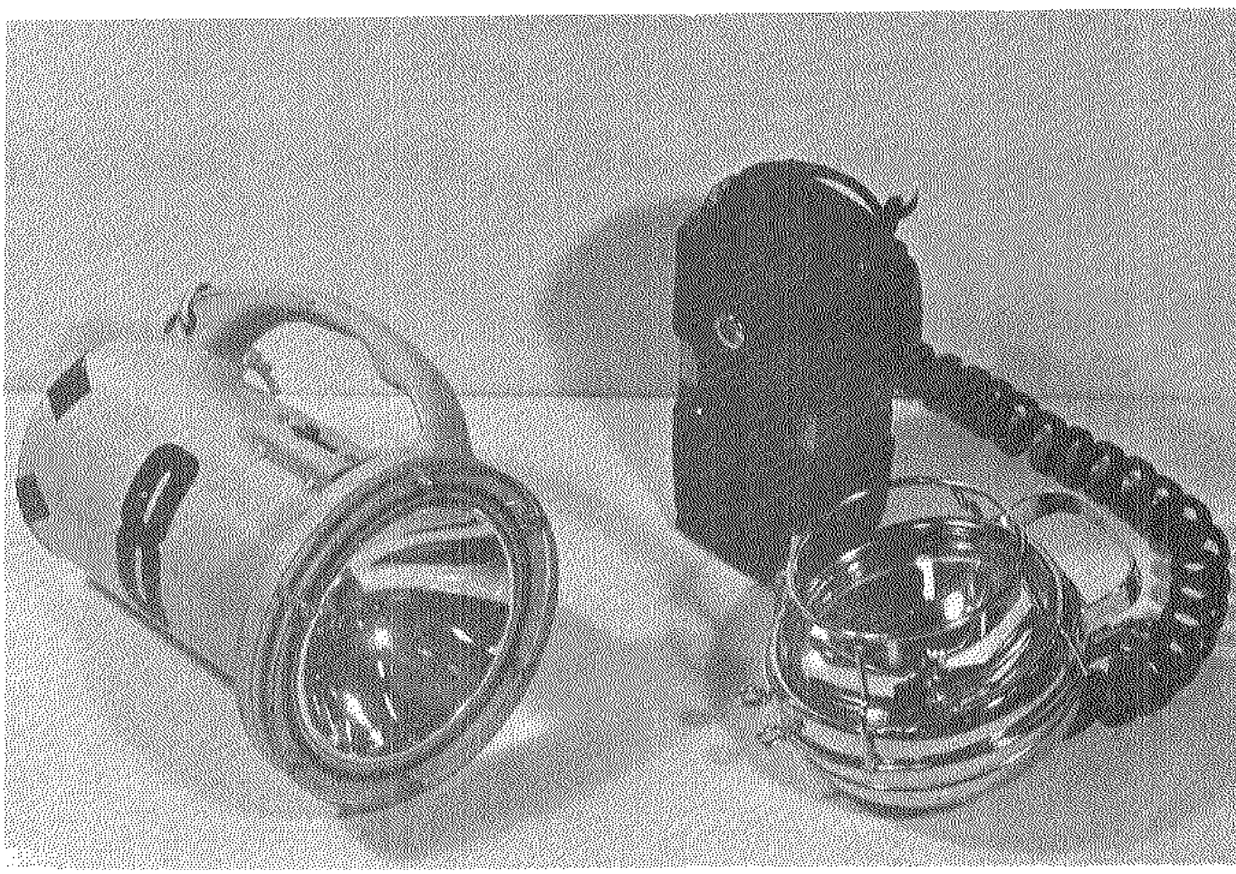

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Figure 6-17. Underwater Hand Lights: (a) Dive Bright 500, Powered by Ten Standard "D"-Cell Batteries; (b) Nickel Cadmium Batteries and Seal Beam Underwater Light, Designed by Somers (Photo by Somers)

Many experienced Florida cave divers design and construct their own lights from nickel cadmium batteries and seal beam lamps (Figure 6-17b). This unit is powered by six nylon, 1.25-volt nickel cadmium, wet-cell batteries. The bulb used is a standard 6-volt automobile spotlight sealed beam. The battery is built by connecting the six cells in series, positive to negative, with wire or metal connectors. The cells are held together by wrapping with plastic tape. The seal beam is contained in a housing which will protect the bulb and connections and provide a means of handling the light. Automobile "plug-in" trouble lamps have been used for this purpose. The 6-volt seal beam in this unit is also satisfactory for underwater use. A two-way, weatherproof switch is placed at a convenient location in the line. A length of two-conductor, insulated wire completes the unit. The most convenient wire is a self-coiling, two-conductor cord. One end of the cord is attached to the positive and negative poles of the battery and the other to the seal beam. A DC battery charger is required for charging the batteries. Charging currents should not exceed amperes required to charge the cell in a period of 1 hr. These lights are extremely powerful, but often lack the durability and dependability of better commercial units.

Some cave divers prefer to use a battery pack attached to a belt or the SCUBA with a sealed beam unit on an extension cord. After using many underwater lights of commercial and homemade varieties, I personally favor an underwater light of the Dive Bright, or equivalent, design. A metal housing is desirable for durability, bulbs are cheaper to replace than seal beam lamp units, and bulb units appear to have the edge in brightness. For the average diver, the "D" batteries are readily available throughout the world, cheaper, and operational maintenance is considerably simplified. The light should be equipped with a lanyard so it can be looped over the diver's arm if necessary, leaving both hands free for line work.

After use, all underwater lights should be washed in clean water and dried. Never leave the lamp head attached to the battery. This prevents possible "shorting out" of the battery, which can happen even if the light switch is in the off position. If the battery is contained in a metal or plastic housing, remove, and stow separately. Inspect before use and keep a spare switch, bulb, and batteries in diving locker.

6.7.11 Observation Boards

6.7.11.1 Slate

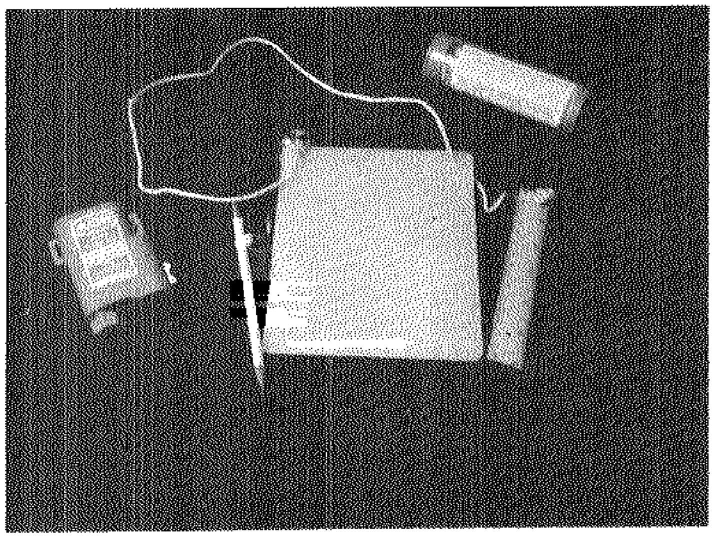
A sheet of 1/8- to 1/4-in. thick plastic with both surfaces roughened with fine sandpaper serves as a writing slate for recording data underwater (Figure 6-18a). A convenient size is 3 in. wide and 10 in. long. An ordinary pencil (#2) is secured to the slate with a length of nylon or rubber cord. The slate may be secured to the diver or his equipment by a lanyard. When a considerable amount of data must be recorded, several sheets of thin, white, roughened plastic may be used with a plastic or metal clipboard.

6.7.11.2 Instrumented Observation Board

The combination of several basic instruments used in research diving into one functional unit has resulted in increased efficiency for observation and data recording. Instrumented observation boards generally are built to individual specifications, the components and dimensions being dictated by mission requirements. The Dowling (1963) board measures 6 x 8 in. and consists of a

- writing board;
- depth indicator;
- compass;
- inclinometer;
- pull-out protractor (with bubble level on one edge);
- ruled edges for measurement;
- bubble levels on two edges;
- holder for two pencils;
- rubber straps on back for attaching folding aluminum (or brass) rule, thermometer, etc.;
- belt clip.

The body of the unit is constructed of a 6 x 8 x 1-in. sheet of Plexiglas. The thickness is necessary to provide recesses for the protractor, inclinometer, and pencils; to allow flush mounting of the depth indicator and compass; and to provide sturdiness. The writing area is covered with 1/16-in., roughened, opaque, white plastic. Two adjacent perpendicular edges are ruled in inches or centimeters, and a bubble level is recessed in one edge. A recessed pull-out protractor, constructed of 1/2-in. Plexiglas, marked in 1-degree increments, and fitted with a bubble level, is hinged to the corner of the board. The inclinometer, a weighted pointer suspended in a hollow 90-degree sector of the body, is marked in 1-degree increments. Pencils are secured in a recessed hollow under spring tension. The compass and depth indicator are secured in recesses in the top of the body. All metal components must be nonmagnetic so they do not affect the compass. Rubber straps are attached to the back of the board for securing additional instruments.



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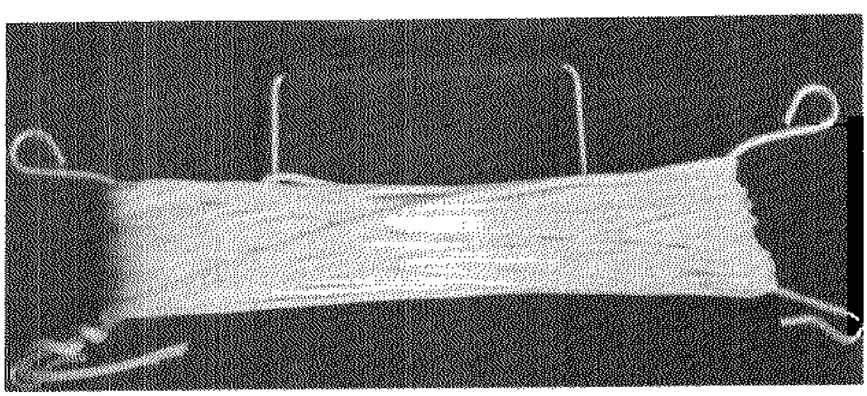

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Figure 6-18. Accessory Equipment for Skin and SCUBA Divers: (a) Left to Right: Rescue Light, Underwater Slate with Pencil and Scale, and MK-13, Mod 0 Day and Night Flare; (b) Line Retainer (Photos by Somers)

The board may be secured to the diver by a special belt clip or a lanyard. Details of construction and use of the instrumented observation board are given by Dowling (1963).

6.7.12 Whistle

A whistle is a valuable item of safety equipment for signaling other swimmers on the surface. When carried, it should be attached to the oral inflation tube of the lifejacket by a short length of rubber strap.

6.7.13 Flare: MK-13

The flare (MK-13, Mod 0, Signal Distress, Day and Night) (Figure 6-18a) is carried taped to the belt or knife scabbard. One end of the flare contains the day signal, a heavy red smoke. The opposite end, which has raised beading around the edge, contains the night signal, a red light. The raised beading enables the diver to locate the night signal when unable to see. Both ends are activated by means of a pull ring. This signal flare is used as a distress signal or as an indicator of the commencement or end of the phases of an operation. After either end of the signal has been pulled, it should be held at arms length and the activated end pointed away from the diver, at an angle of about 45 degrees. The diver's body should also be upwind of the signal. At night, the diver should not look directly at the light because it destroys night vision for several seconds.

The flare will work well after submergence to any standard diving depth. The user should, however, change flares at least every six months or 10 dives, whichever comes first. In the event the flare does not ignite immediately, waving it will cause ignition after a few seconds. The flare will not ignite if pulled underwater.

6.7.14 Rescue Light: ACR-4F

The rescue light (ACR-4F, Fire Fly, Military SDU--5/E) (Figure 6-18a) is carried attached to the diver's belt, harness, or arm. The rescue light is a compact (4 1/2 x 2 x 1-in.; 8-oz), high-intensity, flashing strobe light with an output of 200,000 peak lumens per flash, visible for 10 to 15 miles from 1500 ft altitude. It is completely waterproof and will operate submerged to a depth of 200 ft. With continual use, the light has an operational life of approximately 9 hr. The operational life can be greatly extended by using the light intermittently. The special mercury battery has a 5-yr shelf life. If necessary, the battery can be easily replaced underwater. The unit is designed to withstand heavy impact and shock. Batteries for ACR-4F rescue lights are available from ACR Electronics Corporation, 551 West 22nd Street, New York, New York 10011.

The rescue light is designed for emergency use or diver tracking at night. The diver should not look directly at the light because it destroys night vision for several seconds.

6.7.15 Wireless Communications Systems

Voice communication from diver to diver and diver to surface is required on many research diving operations. Continuous underwater voice communications greatly enhances the safety of the operation as well as the quality and quantity of data acquisition. Currently, direct acoustic transmission and modulated carrier systems are used for most wireless units.

Direct acoustic transmission of sound underwater is the simplest wireless communication method since it involves nothing more than amplification of the voice and projecting it underwater through a loudspeaker. The transmission is received directly by the diver's ears without special receiving devices. Problems arise with this system because of its very low frequency. Water noises are high and underwater obstructions interfere with transmission. A loud-speaker unit of sufficient capacity to handle the low frequency and high power necessary for long-range transmission is relatively large in size. This factor makes the system impractical for divers to wear underwater. However, powerful units may be used under favorable environmental conditions to transmit information from the surface to divers in the immediate vicinity of the loud speaker. This is useful for diver training.

One of the best methods of underwater transmission is the use of a modulated carrier frequency. Three schemes currently used are amplitude modulation (AM), frequency modulation (FM), and single-sideband (SSB) amplitude modulation with suppressed carrier.

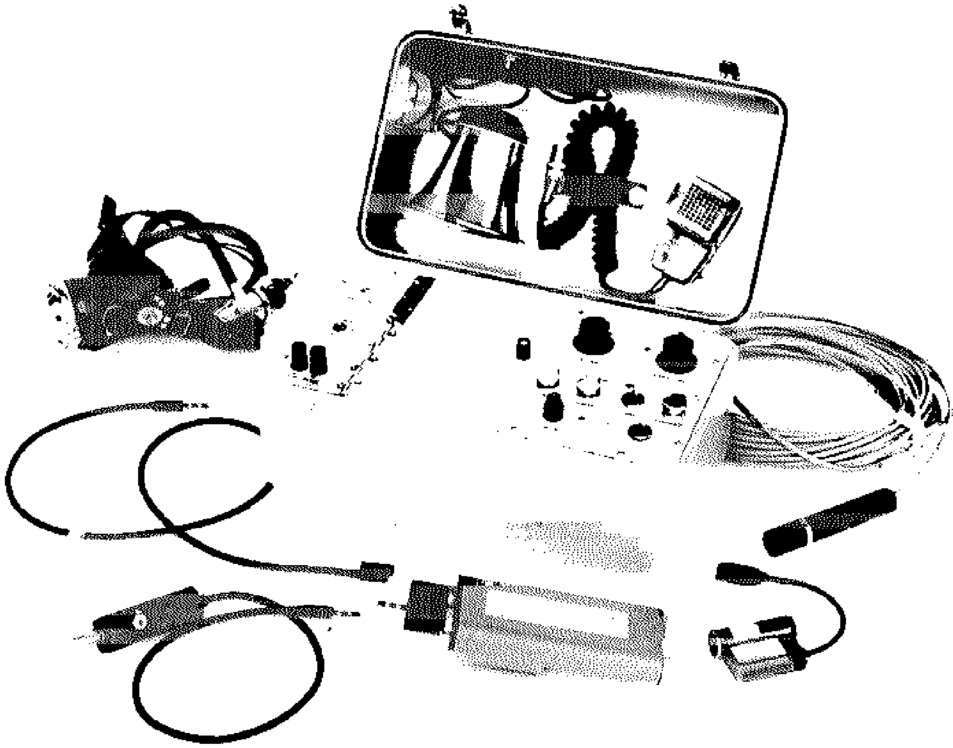
AM and FM techniques are the same as for ordinary radio except for the frequency of transmission and the antenna used. In AM and FM units the voice is picked up from the microphone, amplified, and used to modulate the amplitude of a higher carrier frequency (AM) or vary the frequency of a higher carrier frequency (FM). The signal is projected and later received by a transducer (surface station or another diver) for transformation back into audio or voice frequencies. Carrier frequencies must be selected to handle the voice frequency band width and transmission characteristics of the water. AM is more widely used because the higher FM carrier frequencies necessary for voice transmission have higher absorption characteristics in water and are limited in range, and FM electronics are more complicated than AM. An optimum AM carrier frequency, compromising between water noise and absorption, is about 40 kHz. Compact units operating on this frequency are satisfactory for a communications range of several hundred yards.

A single-sideband suppressed carrier (SSB) uses a lower frequency to provide greater transmission efficiency and range. SSB is similar to AM except that after the voice has modulated the carrier, the carrier is removed, and the resultant signal is amplified, filtered, and transmitted. In the receiver the carrier must be reinserted to obtain the original voice frequencies. Using a frequency near 8 to 10 kHz, ranges in excess of several thousand yards have been reported using a self-contained diver unit. Higher frequencies (28 to 33 kHz) provide excellent short-range communication.

Self-contained diver units and surface units are shown in Figure 6-19. Special lip enclosure mouthpieces or full-face masks equipped with waterproof microphones are necessary for proper articulation when speaking. Waterproof, bone conduction earphones are commonly used.

For more information, consult Hydro Products, a Division of Dillingham Corporation (1969). Other references are Kenny (1966) and Hollien (1967, 1968).

Many divers are frequently disappointed with the quality and intelligibility of underwater wireless voice communications. Tests have indicated an upper level of 52.3 percent intelligibility for selected wireless units (Hollien, 1968). With practice and proper procedures, satisfactory results have been obtained by University of Michigan research divers. Success is largely dependent on diver technique. When transmitting, the diver must speak slowly and distinctly, using simple words and short sentences. He should avoid lengthy and unnecessary transmissions. The lip enclosure mask must be completely free of water or the listener will receive an extremely garbled transmission. The diver must also be certain that his bone-



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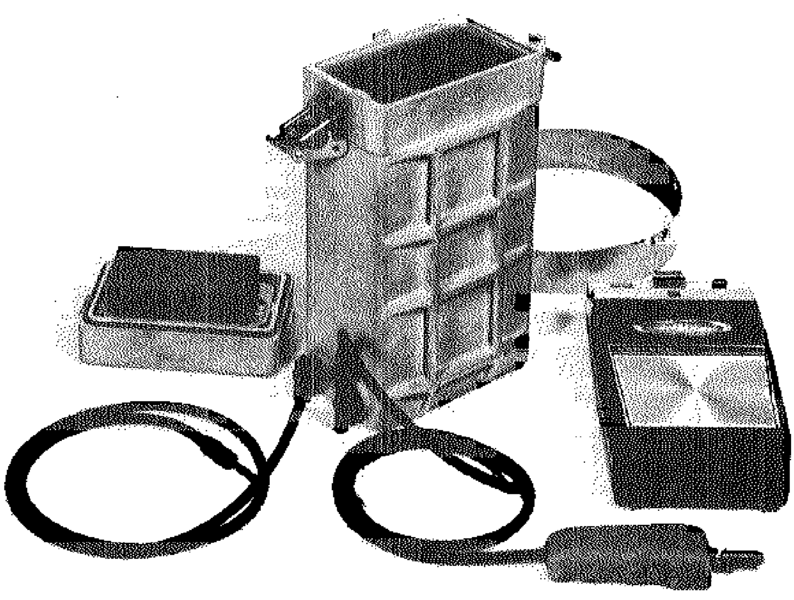

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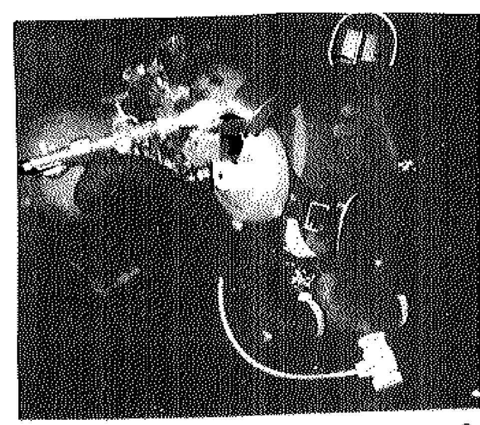

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Figure 6-19. Wireless Underwater Communications Systems: (a) Aquasonics Wireless System: (Left to Right) Mouthmask and Regulator, Switch, Transmitter, Surface Unit, and Receiver; (b) Underwater Tape Recorder; (c) Subcom Wireless Communicator (Photos a and b Courtesy of Hydro Products; c, Courtesy of Subcom Systems Ltd.)

conduction earphone is placed directly behind or in front of the ear. If an audio earphone is placed over the ear, unnecessary layers of neoprene should be avoided. Proper pressure equalization in the diver's ears is necessary to avoid interference with sound wave action on the eardrum. Diver-to-surface communication will be greatly enhanced if the same surface communications man is used throughout the operation. A transmission will be 20-50 percent more intelligible to a tender who is accustomed to listening to a particular diver than a person listening to that diver for the first time.

In addition to diver-surface communications units, small self-contained cassette tape recorders in waterproof housings are used by many research divers (Figure 6-19b). Utilizing the same lip enclosure mouthpiece with a microphone arrangement as used in the wireless units, the diver can record underwater observations. A control switch activates the recorder only when the diver desires to record in order to conserve recording tape.

6.7.16 Equipment Bags and Boxes

All divers should have some sort of bag for transporting and stowing equipment. Equipment bags are generally constructed of heavy cotton or nylon canvas, or vinyl with snap, drawstring, or zipper opening. Various sizes and shapes are available to fit the individual's needs; however, the bag should be large enough to accommodate all of an individual's gear for normal diving with the exception of SCUBA cylinders.

Some divers use large, rigid, plastic containers (such as waste baskets or garbage containers) with tops to transport and stow gear. Regardless of the type of bag or container, the weight belt should be placed at the bottom of the container or transported separately. Regulators, decompression meters, depth indicators, compasses, cameras, etc. are frequently stowed in a separate, padded, rigid container for protection from abuse during transport.

When equipment must be transported or shipped long distances, it is desirable to use shipping boxes. These boxes may be constructed of wood, metal, or plastic to individual specifications. They are extremely useful for stowing gear aboard ship.

6.7.17 Surface Floats

Many divers tow surf mats, surf boards, inner tubes, or similar floats when swimming offshore. The float is used for carrying equipment, samples, catch, or as an object on which to rest. It is a very useful item of rescue equipment. The float is towed on a piece of nylon line which should be coiled on some sort of reel or line retainer. Line length will depend on the diver's depth and personal preference. The float should be fitted with a short pole and diver's flag. A small hook-type anchor is useful for anchoring in kelp or rock.

Small surface floats, 6-in. diameter net floats or equivalent, are useful for training purposes or when working near a support vessel. These floats enable surface personnel to keep track of the divers. One float per two-man team is sufficient. These floats may also be fitted with a diver's flag or a small light for night operations.

6.7.18 Net Sample Bags

Various-sized nylon net bags with top spreaders and handles are available for carrying samples. Large-size bags may also be used for transporting and stowing equipment.

6.7.19 Diver Propulsion Vehicle

The diver propulsion vehicle (DPV) is useful for self-contained divers who must make long-distance underwater survey tracks or travel long distances from a boat or shore base to an underwater work site. Basically, the DPV is a small hand-held cylinder with a propeller on one end. The propeller is driven by an electric motor supplied with power from rechargeable batteries. The amount of thrust will vary with each model; however, one popular model delivers 30-35 lb of thrust at full power. The power thrust may be varied, on some models, from 5 to 35 lb. The units are generally constructed of aluminum alloy. Two 12-volt batteries (in series) provide power for about 1 hr of operation at full power. The DPV is held by pistol-grip handles forward and below the diver's body so that the thrust pushes water under the diver, not in his face. McKenney (1971) discusses one such DPV in detail.

6.7.20 Shark Defense Device

When working in areas of high shark populations (Indo-Pacific, etc.), some self-contained divers carry a device to defend themselves against shark attacks. Many use a simple 4- to 5-ft long, rigid pole with a nonslip blunt end; this is commonly called a "shark billy." Others carry a 4- to 6-ft long pole fitted with a special chamber and firing assembly device in which a shotgun or high-caliber pistol shell is inserted. This assembly is pushed against the head of the shark, the firing assembly automatically activates, and the shell is fired. Needless to say, these devices may be extremely dangerous if mishandled.

Recently, a compressed-gas injector device has been developed and successfully tested. Many individuals feel that this is the safest and most effective defense against sharks. The device, known as a "shark dart," consists of a stainless steel, sharply pointed, 5/16-in., hollow needle slightly over 5 in. long; a CO_2 cylinder holder; and a firing mechanism. When the dart strikes and penetrates the shark, the CO_2 cylinder is jammed against a point and punctured to release the gas into the body cavity of the shark. The expanding gas ruptures the shark's internal organs and forces it toward the surface due to a sudden buoyancy change. The dart may be fitted to the end of a pole or used as a dagger. Different sizes of cylinders are used for different depths. For a detailed description, see McKenney (1972).

6.8 SCUBA Diving Procedures

Basic diving procedures have been discussed previously; however, certain procedures unique to self-contained diving are included in this chapter. First, all aspects of the mission must be evaluated to determine whether to use self-contained diving or surface-supplied diving techniques. Environmental conditions unfavorable for self-contained diving include extremely poor underwater visibility, strong currents, cold water, ice cover, and contaminated water. Under these conditions, use surface-supplied diving techniques if possible. Self-contained divers should avoid entry in heavy surf. If dive depth and duration require decompression, surface-supplied diving techniques are preferable.

6.8.1 Personnel

The responsibilities of the diving supervisor, surface personnel, tenders, and divers have been discussed previously. Frequently, SCUBA diving operations will involve only two divers and one surface crewman. It is unwise to conduct any diving operation without at least one person remaining on the surface to aid divers before and after the dive and to tend the surface vessel.

6.8.2 Minimum Equipment

The minimum equipment for a SCUBA diver consists of

- swimsuit,
- lifejacket,
- knife,
- swim fins,
- face mask,
- SCUBA.

Many SCUBA divers prefer to carry a snorkel to facilitate surface swimming when returning to the boat or shore with exhausted air supply. When diving to depths in excess of 50 ft, a waterproof watch and depth indicator (gauge) are required. A weight belt is required when wearing an exposure suit. Details on accessory equipment have been discussed.

6.8.3 The Buddy System

The use of the buddy system is the greatest single safety factor in self-contained diving. No self-contained diving operation should be undertaken without the use of the buddy system. This safety procedure requires that the divers work as a single unit. Each member of the buddy team is responsible for his partner's safety throughout the dive. Both have joint responsibility for completion of the mission assigned. The divers must maintain continuous contact with each other. When visibility is good, sight contact at short range is adequate. However, when visibility is poor, a short length of line (buddy line) is necessary for maintaining contact. "Buddies" must learn to work together and should know and understand a standard set of signals. It is best to stay within touching distance when possible without interfering with diver movement.

6.8.4 Hand (Visual) Signals

Hand signals (Figure 6-20) are used by self-contained divers to convey critical information rapidly. The signals recommended by the Underwater Society of America are recommended as "standard" signals. However, a survey of literature and interviews with divers from various parts of the United States reveals discrepancies in the hand-signal system. Consequently, until there is nationwide and/or worldwide agreement on "standard" hand signals, the diving team members must agree on a set of signals prior to the dive. This is best accomplished by the diving supervisor during briefing sessions.

6.8.5 Preliminary Preparation

In addition to general planning, the following procedures should be carried out prior to the dive:

1. Gauge cylinders immediately before entering the water to ensure that there is sufficient air for the dive.
2. Attach regulator and open cylinder valve to determine if there are any leaks in the SCUBA.
3. Inhale and exhale through the mouthpiece (or mask) to ascertain that the SCUBA is functioning properly.
4. Inspect breathing tubes, harness, etc. to ensure that the unit is properly assembled.
5. Close the air reserve mechanism.
6. Inspect lifejacket and its gas cartridge to ensure readiness for operation.
7. Don accessory equipment.
8. Don SCUBA and secure harness properly to ensure quick release in an emergency. Diving partner and/or surface personnel will aid with donning SCUBA.
9. Check diving partner's equipment and finalize (or review) dive plan.

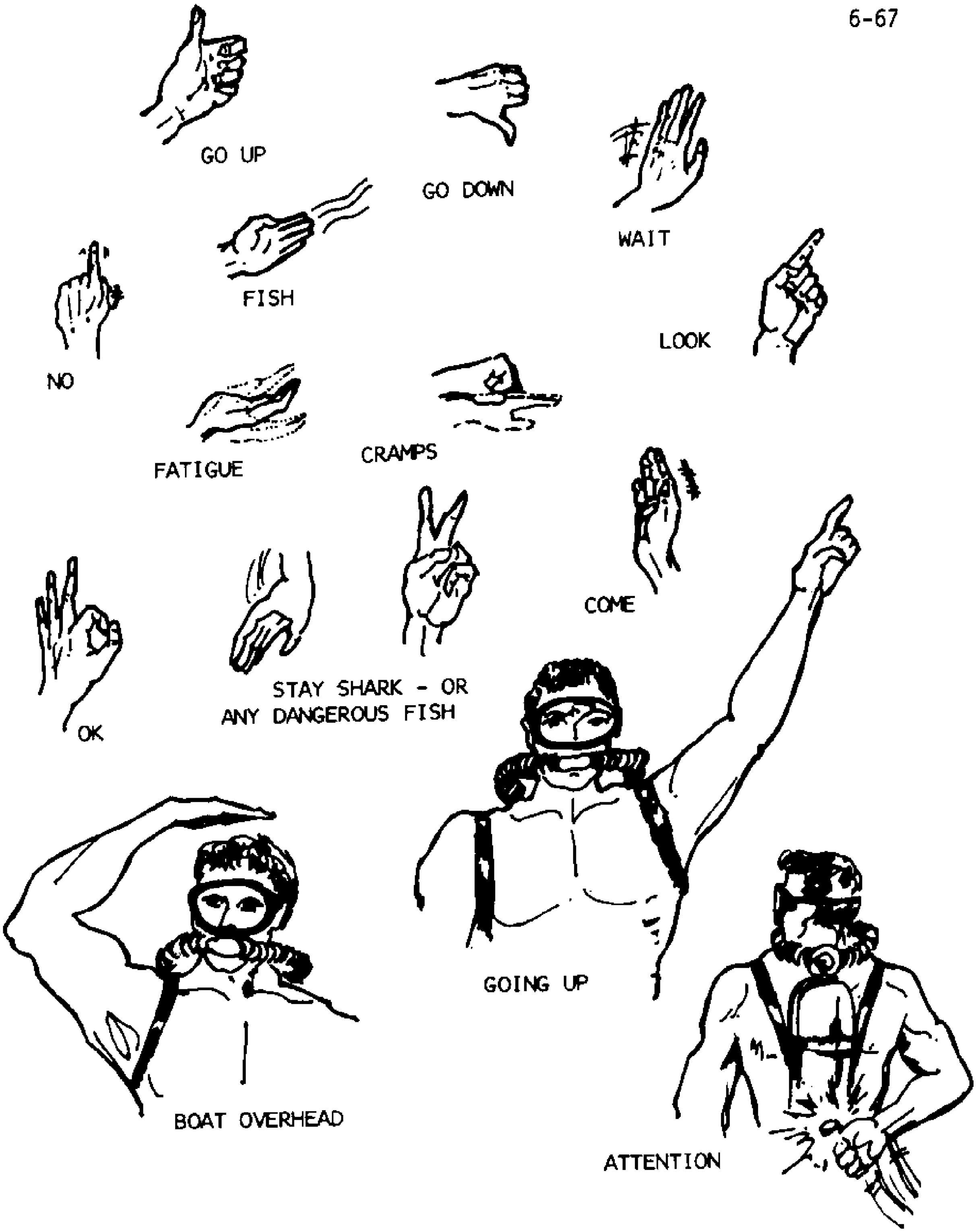

Figure 6-20. Hand Signals for SCUBA Divers as Recommended by the Underwater Society of America

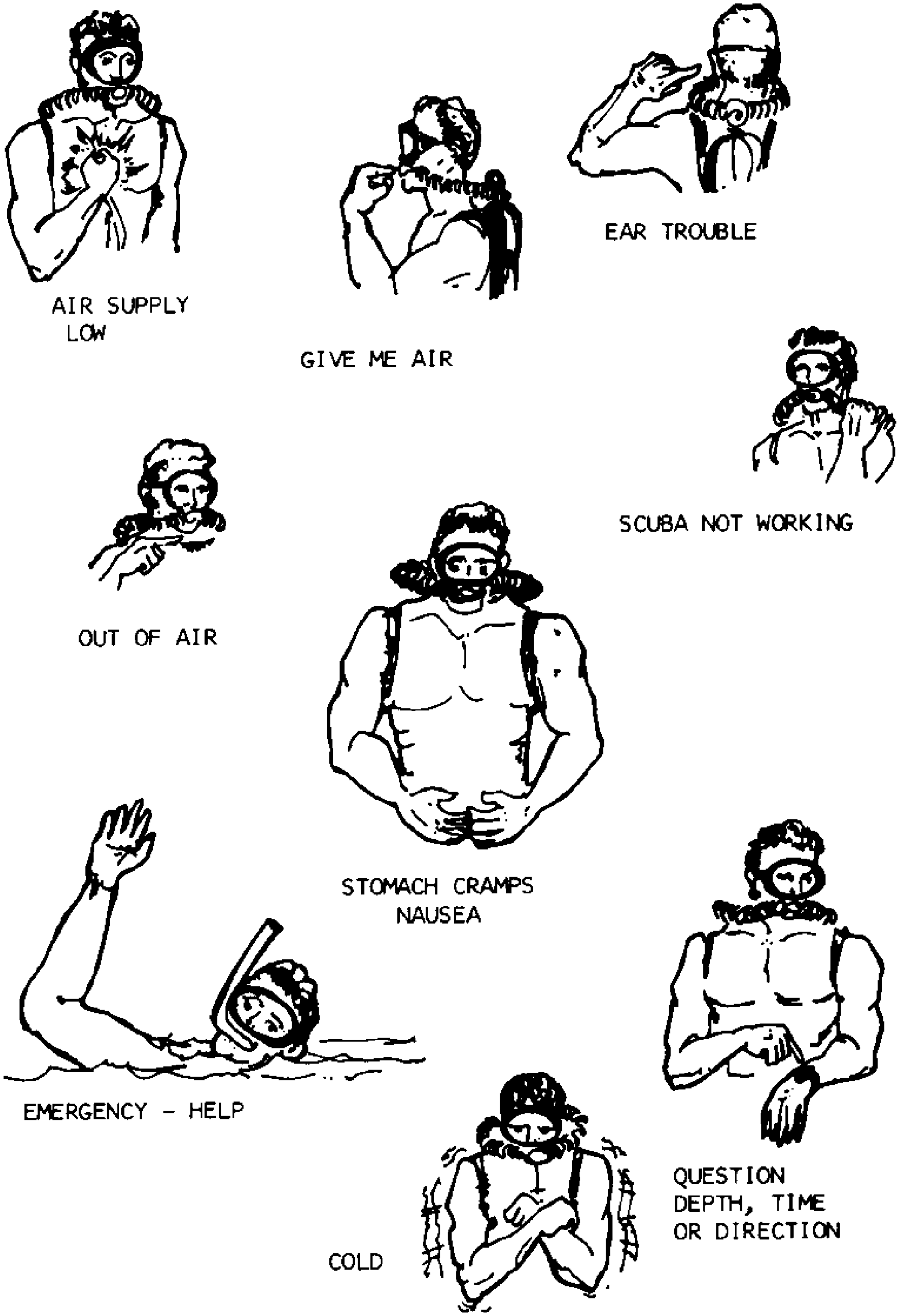

Figure 6-20 Continued

10. Prepare to enter the water after clearance from the diving supervisor.

6.8.6 THE DIVE

Both divers will enter the water at the same time. Entry techniques will depend upon staging area or type of vessel. Upon entering the water, the divers will stop at the surface to

- make a final equipment check;
- adjust buoyancy if necessary;
- check SCUBA operation and inspect partner's SCUBA for leaks;
- check to ensure that your partner's reserve mechanism is closed (lever in up position);
- report any inadequacies or malfunctions of equipment to your partner and the diving supervisor. *Correct* any deficiencies before making the descent. If deficiencies cannot be corrected simply and immediately, *abort* the dive.

Upon completion of the final equipment check, the divers will signal each other and the diving supervisor that they are ready to descend. When the divers are ready, the dive supervisor will signal them to commence the dive. The divers will observe the following procedures during descent and while swimming underwater:

1. Descend *together*. If one diver experiences difficulties equalizing pressure, the other diver should stay with him. Although the divers will set their own rate of descent, exceeding 75 ft/min is not recommended.

2. A descent line or anchor line should be used when possible even in clear water. This aids the diver in maintaining depth and controlling descent for pressure equalization purposes.

3. When descending without something to facilitate orientation, some divers experience vertigo, nausea, and severe disorientation. If these conditions develop, it may be necessary to abort the dive.

4. Upon reaching the bottom, the divers must confirm that everything is satisfactory and immediately establish orientation. Previously, one diver will have been designated as leader.

5. Swim against the current so return to the boat or starting point may be facilitated by drifting with the current at the end of the dive.

6. If visibility is limited, the divers may wish to use a "buddy line" and/or a distance line (on a reel) to facilitate return to the descent line. This is especially necessary for proper decompression procedures.

7. Proceed with the mission and avoid excessive exertion. At the first sign of increased breathing rate, fatigue, etc., *stop, rest, and ventilate!*

8. Observe proper buddy procedures and follow the dive plan.

9. The diver should monitor his air supply pressure gauge readout throughout the dive. Terminate when the low-air warning is evident, if not before.

10. When the mission is complete, air supply depleted, or the dive time is up, the divers should acknowledge to each other that it is time to terminate and will proceed to the line or ascend directly at a rate of 60 ft/min. Both divers must ascend together. Never leave one on the bottom to complete the mission even though he may have sufficient air. Make decompression stops as previously determined in the dive plan.

6.8.7 Postdive Operations

The divers should be helped from the water and with removal of equipment by surface personnel. Observe the divers for signs of sickness or injury resulting from the dive and commence warming procedures as soon as possible. Undertake preventive maintenance of equipment as soon as possible after the dive. The divers should report any defects noted during or after the dive and the defective equipment should be tagged for corrective maintenance.

6.8.8 Underwater Navigation

Establishing and maintaining orientation underwater is essential for the safety and efficiency of any SCUBA diving operation. Sense of direction is easily lost underwater, especially when visibility is limited and the diver is unfamiliar with the area. Orientation begins at the surface and continues throughout the dive. Proper underwater navigation entails (1) establishing surface orientation relative to the underwater area to be explored and arriving at the bottom with a fixed reference point in mind, (2) establishing orientation on the bottom in reference to this fixed surface point and bottom features, (3) steering a reasonably accurate course on the bottom, and (4) returning to a predetermined point. The fixed reference point on the surface may be a boat, shoreline feature, or man-made structure. Underwater, the reference point may be a prominent natural feature such as a reef area; a man-made structure such as pipeline, cables, or an anchor; the general ripple mark trend; the current; or a combination of these factors. For example, if the ripple marks are orientated parallel to shore, the diver may determine his orientation with respect to shore by observing the ripple marks and relative depth. It should be emphasized, however, that ripple marks are not always orientated parallel to shore and that their orientation should be checked with a compass.

Self-contained divers commonly use a liquid-filled magnetic compass (Figure 6-15d) for underwater direction finding and navigation. Generally, the compass is secured to the diver's wrist; however, it may be carried fastened to a compass board or observation board. A diver's compass should have the following features: (1) correct dampening action, (2) liquid filled, (3) the compass rose marked in degrees, (4) lubber's line showing direction over the face, (5) a course setting line, and (6) a movable bezel. A good compass will respond rapidly to even slight course changes and have a high degree of luminescence for use in dark water.

The wrist compass is generally placed on the wrist (right for right-handed and left for left-handed persons). Other metallic objects that might cause deviation, such as watches, depth gauges, and decompression meters, should be worn on the opposite wrist. When using a compass, the diver will first obtain a bearing in degrees to his target relative to magnetic north. While sighting on the target, rotate movable bezel until the parallel lines on the compass face (movable) are aligned with the North needle. The bearings, in degrees, will be indicated at the end of the North needle. To maintain proper direction while swimming, the diver must keep the North needle aligned with the parallel lines on the compass face.

When swimming underwater, the "compass-lock" position is recommended. In this position the arm without the compass is extended straight in front of the diver, the diver bends his compass arm 90 degrees at the elbow, and then grasps the extended arm near the elbow. This places the compass directly in front of the diver's eyes and aids in keeping the diver's body on a straight line. The two most serious mistakes when using a compass are failure to keep the lubber line parallel to the longitudinal axis of the body and the diver looking down at the compass instead of sighting over the compass. The diver must keep his body straight and swim in a straight line if he hopes to navigate accurately.

The use of a *compass board* will greatly improve accuracy on long underwater swims. US Navy Underwater Demolition and SEAL Team swimmers generally operate well within a 1.3 percent margin of error relative to target (Hemming, 1970); good wrist compass accuracy is about a 5 percent error factor. The compass board is constructed of 1/4- to 1-in. marine plywood, hardwood, or sheet plastic (Plexiglas) with dimensions of approximately 8 x 10 in. One end is rounded to give a more hydrodynamically efficient shape. Better quality compass boards are designed and constructed to be neutral in sea water. The compass may be mounted permanently or the board can be slotted in order to utilize the wrist strap and facilitate easy removal for conventional use. The compass is mounted at the middle of the board directly on the center line. A depth indicator; watch; small, waterproof light; decompression meter; or lanyard may be included in various configurations at the diver's discretion. Hand slots may be cut on each side to facilitate handling.

While swimming, the compass board is held firmly in both hands parallel to the intended direction of travel. The elbows are pressed against the sides of the body for stabilization and the compass board is held about 1 ft in front of the mask. When using a luminous dial compass at night, the compass board may have to be held closer to the face. Prior to submerging, a visual sighting on the target is made and the compass is set. Underwater the compass is observed throughout the swim. If the compass board also includes a depth indicator and watch, these instruments are scanned systematically along with the compass.

Assuming that the diver has swum a straight course, he can return to his original point of entry by following a course 180 degrees opposite his original course bearing with an accuracy of ±5 degrees.

Basic pilotage and dead reckoning navigation can be used by divers. The simplest method of navigation is pilotage. This involves establishing a position in relation to known features and plotting a course toward a destination from a known position. The diver simply determines the bearing and swims on course to a specific point or area. Dead reckoning, however, requires following a compass bearing in a specific direction, taking into account speed and time. An estimated time of arrival (ETA) may be computed.

Approximated distance or time required to swim between two points may be determined by the simple formula: Speed x time = distance. Thus, an ETA can be determined. Distance traveled underwater can be determined by time or counting the number of kicks. On the average, at normal swimming level, a diver wearing a wet suit will travel 2.5 ft/sec or 3.25 ft per kick cycle. The same diver without a wet suit will travel 3.6 ft/sec or 4 ft per kick cycle. The individual can measure his own underwater swimming rate by swimming a given course and recording the time and number of kicks. An average of several swims should be used.

6.9 Emergency Procedures

Emergency situations occasionally arise on even the best planned and supervised underwater operations. Many of these emergencies are the result of failure to observe some safety precaution; others are unforeseen and unavoidable. Very few underwater emergencies are so desperate as to require instantaneous action. Take a few seconds to think! Instinctive actions are seldom right. They may prove to be blind impulses brought on by panic. Adequate training will prepare the underwater swimmer for almost all emergencies, provided that he keeps his head. Do not panic and, above all, never abandon your breathing apparatus underwater unless ascent is impossible without doing so.

6.9.1 Exhaustion of Air Supply

This should be no problem to the properly trained and equipped diver. When breathing resistance becomes noticeable, simply open the air reserve mechanism and start ascent. Even if the reserve fails, increased breathing resistance prior to exhaustion of air supply gives some warning. Do not panic and ditch the SCUBA! The reduction in pressure and subsequent gas expansion during ascent provides additional air for breathing. The emergency ascent or "free ascent" is a last resort. All divers should experience exhaustion of air supply during training!

6.9.2 Loss or Flooding of Face Mask

The self-contained diver must learn to swim underwater without a face mask and how to purge water from the mask in the event of flooding. If the mask becomes dislodged and partially or completely fills with water, it should be repositioned on the face and purged of water by tilting the head backwards to place the lower edge of the mask at the lowest position. The diver then presses the upper portion of the mask firmly against the forehead and exhales through his nose. The exhaled air will displace the water and force it out under the lower edge of the mask.

If the mask is equipped with a purge valve, simply position the head so the purge valve is in the lowest position relative to the rest of the mask and exhale through the nose. Some divers prefer to press the top portion of the mask against the face while purging to limit the loss of air.

6.9.3 Purging Water from the Breathing System

There are various methods of purging water from flooded mouthpieces and hoses. Each method should be mastered and the trainee should learn the procedure for both double- and single-hose units.

The simple method is to place the mouthpiece in your mouth and exhale. This will generally purge the water from the assembly and restore free breathing. Inhale cautiously following the purging procedure to be sure that all water is out. When purging the single-hose regulator, position the exhaust valve so that all water will drain through it. This may require the diver to look straight ahead or tilt his head slightly backward. Turning the left side down so that the water will run into the exhalation hose will facilitate clearing two-hose regulators.

If the diver does not have enough air in his lungs to expell the water, he will have to use the "free-flow" method. In two-hose units, the air will flow freely through the mouthpiece when it is raised above the level of the regulator housing. Therefore, raise the mouthpiece above the housing until it free flows, turn the mouthpiece down to trap air in it, tilt the head back, insert the mouthpiece into the mouth while free flowing, and resume breathing. The same method may be used with a single-hose regulator; however, a purge button must be depressed to initiate the free flow of air. An alternate method of purging a single-hose regulator is to place the tongue into the air inlet opening and depress the purge button. The water is forced out through the exhaust valve.

The diver should be alert for the cause of the flooding of the system. Some problems such as damaged breathing tube, diaphragm, or exhaust valve may hamper successful clearing of the system.

6.9.4 Recovery of Lost Mouthpiece

When the mouthpiece of a two-hose unit is lost, it will float to the highest point. When in the swimming position, the diver should bring his feet forward and lay on his back. The mouthpiece will be directly above his face. Single-hose regulators generally lead over the right shoulder. If the mouthpiece is dropped, the diver should reach back, feel the first stage of the regulator, and follow the hose to the second-stage mouthpiece. The use of a neck strap to retain the regulator in front is discouraged; harness clips are permissible as long as they release readily for sharing air in emergencies.

6.9.5 Entanglement

The diver's knife is his safeguard against entanglement. The entanglement situation generally requires more thought than action. Do not struggle; this may only increase the degree of entanglement. This is where the "buddy system" is useful. The buddy can carefully cut the entangled diver loose. Only as a last resort should the diver remove his breathing apparatus and make a "free-ascent."

6.9.6 The Role of the "Buddy" in Underwater Emergencies

"Buddies" must learn to work together and should know and understand a standard set of signals. They should be in visible range at all times and observe each other. In poor visibility a short buddy line may be required. The diver should signal his "buddy" at the first sign of trouble. If your "buddy" shows signs of distress, get to him at once whether he signals or not. The hardest job for a "buddy" will be in the presence of panic. You may be able to do no more than take him to the surface at once. In handling a panicked or unconscious person underwater every effort must be made to keep the mouthpiece in place. In ascent, the possibility of air embolism exists. It may be necessary to tilt the victim's head far back to facilitate exhalation, especially in panic situations. Never strike the victim in the stomach or chest; this procedure could cause an air embolism.

It may be necessary for SCUBA divers to share air (buddy breathe) in the event of air supply exhaustion or equipment malfunctions. There are several methods of sharing air and the diver must use the one best adapted to the situation. Generally, air sharing is necessary only for direct ascents. The divers simply face each other and exhange the mouthpiece of the operative SCUBA while making a slow, controlled ascent. When sharing air with a single-hose regulator, the diver providing the air should be slightly to the left (when facing the stricken diver). Do not fill your lungs and then hold your breath while your "buddy" is taking a breath! Remember you are ascending and that you must continue to exhale as you rise to prevent air embolism. The diver supplying the air should always retain control of the mouthpiece and grasp the harness of the victim. He is generally in a better position to regulate breathing cycles and to control the ascent than the diver who has experienced air supply failure.

When working in caves or under ice, divers may find it necessary to move in a lateral direction before ascending to the surface. In this case the diver wearing SCUBA containing air swims with his left side down. The distressed diver swims on his right side, holding his "buddy's" harness with his left hand and exchanging the regulator with his right.

An alternate method of lateral swimming is for the "buddy" with the air supply to swim face down. The other diver swims directly above him holding onto the neck of the air cylinder. The diver on the bottom passes the regulator up and the top diver places it back in view of the bottom diver. These methods may be used for both double- and single-hose regulators. Another method of lateral swimming while sharing air with a single-hose regulator is to•have the divers swim side by side in a prone position.

Sharing air under emergency conditions is difficult even for the best trained and most experienced divers. Divers should practice the skill frequently. Furthermore, the use of auxiliary breathing systems is encouraged.

6.9.7 EMERGENCY ASCENT

Learning the technique of an "emergency controlled swimming ascent" is an important part of training; however, this ascent should only be used as a last resort to resolve an emergency situation. It is hazardous and difficult to accomplish safely in situations of stress.

Unless the breathing apparatus is entangled, the diver should not abandon it even though it may be useless. The diver should not initially drop his weights; this could result in an uncontrolled ascent. He must exhale prior to the start of the ascent and continue to exhale throughout the ascent. The head should be extended back. This allows maximum opening of the throat area and a good overhead view. The diver should *swim* to the surface, constantly being aware of possible entanglements or obstructions, and of the consequences of holding his breath. The mouthpiece may be left in place. The weight belt should be dropped if the diver is having difficulty swimming to the surface. Definitely, drop belt at the surface to facilitate staying afloat.

Training for emergency controlled swimming ascent is a serious and hazardous exercise. Students should make proper supervised ascents in a swimming pool first. At first the mouthpiece should be left in place. For later ascents, the mouthpiece can be removed and held by the diver. Long free ascents may be simulated by having the trainee swim the length of the pool while exhaling in an emergency controlled swimming ascent fashion. The same procedure should be followed if emergency ascent training is conducted in open water. The instructor and trainee should surface facing each other with the instructor close enough to control all phases of the ascent and give aid if necessary. Practice first in shallow water and progress to deeper water at the discretion of the instructor.

In desperate emergency situations where the diver feels that he may pass out, etc., it may become necessary to make a positive buoyancy ascent and risk entanglement, injury, and air embolism. This is accomplished by dropping the weight belt and/or inflating the lifejacket (only high-capacity lifejackets are dependable).

The ascent will be slow at first and will become more rapid as the wet suit or lifejacket expands, especially near the surface. A few kicks may be necessary to initiate the ascent. *Positive-buoyancy ascents are to be used only in a life-or-death situation, and no others! Remember, in all emergency ascents, exhale continuously throughout; the possibility of air embolism is always present.*

6.9.8 At the Surface

Upon reaching the surface after emergency ascent, or when in trouble at the surface following normal ascent (rough water, exhausted, etc.), jettison the weight belt, inflate the lifejacket, and signal for pick up. When a long distance from assistance, it may be necessary to use the signal flare to attract attention. The surface crew should be alert for divers in trouble at all times.

When not in difficulty, swim for the craft or shore base. If the breathing apparatus interferes with swimming, the diver should remove the equipment and tow it to safety while swimming on his back (jacket inflated or deflated) or on his front with a snorkel. The diver may have to ditch his equipment if he faces a long swim to safety.

The above procedures and skills must be mastered during training. Various exercises are used to test the trainee's ability to cope with underwater situations. Empleton (1968) covers basic SCUBA training.

6.9.9 Drowning

The US Navy considers drowning to be the most frequent cause of death in self-contained diving. Drowning may result from simple mechanical malfunction of equipment, but is most frequently the result of underwater accidents and environmental factors. The most common cause is physical exhaustion resulting from swimming on the surface after the air supply has been depleted. Surface swimming in rough seas is an even greater hazard. Another primary cause of drowning is the inability of the diver to cope with emergency situations. Any of these conditions may result in panic and consequent drowning. Any underwater accident that causes unconsciousness generally results in drowning.

Self-contained divers must take every precaution to prevent drowning. The following preventive measures must be considered by all self-contained divers:

1. adequate training with drill in emergency procedures;
2. good physical condition;
3. *use of a lifejacket at all times*--with or without SCUBA;
4. proper maintenance, and use of approved equipment only;
5. good diving practices with adequate preparation;
6. knowledge and observance of personal limitations;
7. provisions for aiding divers in distress (keep someone in the boat at all times);
8. training in lifesaving and water safety;
9. training of each person in the use of artificial respiration.

6.10 Lifesaving Procedures

Since self-contained divers spend more time in the water under more hazardous conditions than do most swimmers, it is essential that they know the fundamentals of lifesaving and water safety. One of the first principles of water safety is fulfilled by the "buddy system"--*never swim or dive alone.* Divers have another important factor in their favor--the lifejacket. Through the "buddy system" and the use of a lifejacket, most situations can be resolved.

The additional equipment used by skin and SCUBA divers modifies, to some degree, lifesaving techniques. The fact that the "buddy" is generally always in the water, near the victim, lessens the use of a reaching or throwing assist. It is a known fact that most divers get into trouble at the surface, rather than at depth. In "trouble" situations the "buddy" is normally obligated to render all assistance possible. Frequently, "trouble" situations may develop into panic situations.

6.10.1 Trouble Situation

In the "trouble" situation, the diver is simply having difficulty in keeping afloat, but he has not lost control of himself. The victim may rescue himself by jettisoning his weight belt, inflating his lifejacket, or regaining physical control of the situation. In this situation the buddy can do several things. If there is no float to push to the victim or other means of avoiding contact, the rescuer must move in, *staying behind the victim!*

The safest and simplest means of aid is to reach around and inflate the victim's lifejacket. If he is not wearing a lifejacket or if this method is not feasible, the rescuer should support him at the surface by gripping him firmly under the arm or by the cylinder while talking to him and thus enabling him to get his breath. *If the victim is wearing a weight belt, the rescuer should jettison it. He should also jettison the SCUBA if necessary. The rescuer should reassure the victim and keep calm!* A calm reassurance can often prevent a panic situation.

6.10.2 Panic Situation

Panic is a sudden unreasoning and overwhelming fear which attacks people in the face of real or fancied danger. Panic is the diver's most deadly hazard and is a contributory cause of practically all water accidents. A panic situation is dangerous to both victim and rescuer. The rescuer must know what he is doing and apply all his skill and training to avoid personal danger. *The will to aid sometimes ends tragically for both victim and rescuer!* The first impulse of a panic-stricken swimmer will be to "climb" the rescuer and get himself out of the water. The rescuer must retain his common sense, good judgment, and reasoning, and *must not let the victim get a hold of him--stay clear.* While the victim is violently thrashing in his panic, these movements will probably keep him afloat. When he tires, the rescuer can move in from behind and proceed with the rescue as in the "trouble" situation. The rescuer must be sure to keep the victim facing away from him so the victim cannot grab him. By holding the diver firmly under the arm or by the cylinder the rescuer can both hold him up and control him. He should jettison the victim's weight belt as soon as possible.

6.10.3 Approach

If it is necessary *to approach the victim from the front,* the rescuer should swim to within 6-8 ft of him. He should do a surface dive and approach the victim underwater, grasping him at the knees and turning him around. From the moment the rescuer makes contact with the victim, he should keep hold of him and control him. He should drag the victim underwater as he moves up to a support or carry position. When *approaching from the rear,* the rescuer should be in a position to move quickly out of the victim's reach in case he turns. He should use the underarm grasp and control if necessary.

6.10.4 Equipment Aids

The fact that divers are equipped with mask and fins can greatly facilitate rescues. The addition of the lifejacket simplifies the situation considerably. SCUBA may be an advantage or disadvantage. The rescuer should not inflate his personal lifejacket until the situation is in hand and he knows he will not have to go underwater to approach or maneuver his victim. If he does inflate his jacket and find that he must go back underwater, he should remove it and leave it for a float. If he cannot remove it, he should deflate it.

6.10.5 Towing

Once the victim is under control, the rescuer should *tow him to safety*. The simplest method of towing the victim is for the rescuer to grasp the collar of the victim's inflated lifejacket and swim on his side or back, towing the victim at arm's length. He should take care not to kick the victim. The important thing is to keep the victim's head above water. The rescuer should keep control of the victim at all times. If the victim is struggling, the rescuer may wish to place one hand under his arm for control. The rescuer should *not let the victim turn on him.* If the victim does not have a lifejacket, but SCUBA, the rescuer should grasp the cylinder firmly and follow the same procedure. For a swimmer with no lifejacket or tank, the rescuer should grasp him firmly under the arm with one hand and push him to a horizontal position with the other. Then quickly swing the free arm over his shoulder, across his chest, and under his arm. *Hold firmly!* In this position the rescuer will probably not be able to use his vest inflated. If the victim struggles, the rescuer should clamp both arms around him and move with him. He should never let go with the control hand under the arm until he has completed the cross-chest carry. An alternate method of towing is the *head carry*. The rescuer can use his personal lifejacket (inflated) when doing this carry. The rescuer places a hand on each side of the head. The palms cover the victim's ears, the fingers are extended along the jaw and the thumbs are placed on the temples. He holds firm and depresses his wrist to tilt the victim's head back. The rescuer holds his arms straight and swims on his back.

6.10.6 Assist

As previously stated, the fact that the "buddy" is generally always in the water, near the victim, lessens the possibility of reaching or throwing assist. However, it should be stated that if at all possible, contact with the victim should be avoided. If near a pier, boat, etc., the rescuer should reach for the victim with hand, towel, pole, or whatever may be handy. If the victim is too far away for a reaching assist, the rescuer should throw a rope, ring buoy, etc. If the rescuer reaches for the victim, he should keep low and firmly placed so the victim will not pull him in. The prone position is best.

6.10.7 Releases

If, for some reason, the victim gets a hold of the rescuer, the rescuer must know how to break it. Holds can sometimes be prevented by blocking the arm, grasping it, and turning the victim around; go directly to a control and carry position. Other times, it may be necessary to block the victim by ducking underwater, placing the hand on the victim's chest and pushing him away. When the victim actually gets a hold on the rescuer, the rescuer should not panic. He should *sink, think, and act!* If the victim gets a front head-hold on the rescuer, he should submerge, grasp the victim's arm (on the side closest to his head) at the elbow, and push up. He should bring his other hand over the victim's arms, between his own head and the victim's, and push the victim's head away. When the victim breaks, retain the hold on his arm, turn him, and control him. An alternate method of escape is for the rescuer to sink, place both of his hands on the victim (grasping his sides), and push outward and upward, while turning his own head to the side. When the victim breaks, turn and control him. If the victim gets a rear head-hold, the rescuer should sink, grasp the lower elbow and wrist, and push up on the elbow and down on the wrist. As the rescuer frees himself, he he should move under the victim's arm (retaining hold) and control him. If the victim grabs his arm, the rescuer should release the hold with a quick twisting jerk of his arm. The rescuer should use leverage to advantage in all breaks.

6.10.8 After Rescue

Once the rescuer has towed the victim to safety, he should get him out of the water and treat him for shock. Following serious panic, it is often best to consult a physician before moving the victim. If the victim is unconscious, but breathing, he should be treated for shock and a physician definitely consulted. When a nonbreathing victim is recovered, artificial respiration should be started at once. The rescuer should inflate lifejacket and administer mouth-to-mouth or chest pressure/arm lift artificial respiration while swimming to shore. See directions in the sections of first aid and artificial respiration.

6.10.9 Mouth-to-Snorkel Rescue Breathing

In deep water the snorkel may be used as an aid for administering artificial respiration. Once it has been determined that the victim is not breathing, immediate artificial respiration is mandatory. The time lost in returning to shore to do this may be critical and may result in death. Pierce (1971) recommends the following procedure for a rescuer who is administering artificial respiration while swimming in deep water:

1. Turn victim face up, inflate lifejacket, and tilt head sharply back with a chin pull to open airway.
2. Clear water from snorkel and insert mouthpiece in his mouth. Use the fingers and palm of the chin pulling hand to seal the mouth and use the thumb and forefinger of the same hand to pinch the nostrils shut.
3. With your other hand controlling the tube end of the snorkel, place it in your mouth and blow; watch the victim's chest rise.
4. Remove the tube from your mouth and listen to air flow out.
5. Repeat, as in mouth-to-mouth artificial respiration while towing victim to shore. You may inflate your lifejacket, if desired.

6.10.10 Lifesaving and Water Safety Training

All divers are encouraged to acquire training in lifesaving and water safety through the American National Red Cross, YMCA, or an equivalent organization. An authoritative discussion of the subject is given by Silvia (1965).

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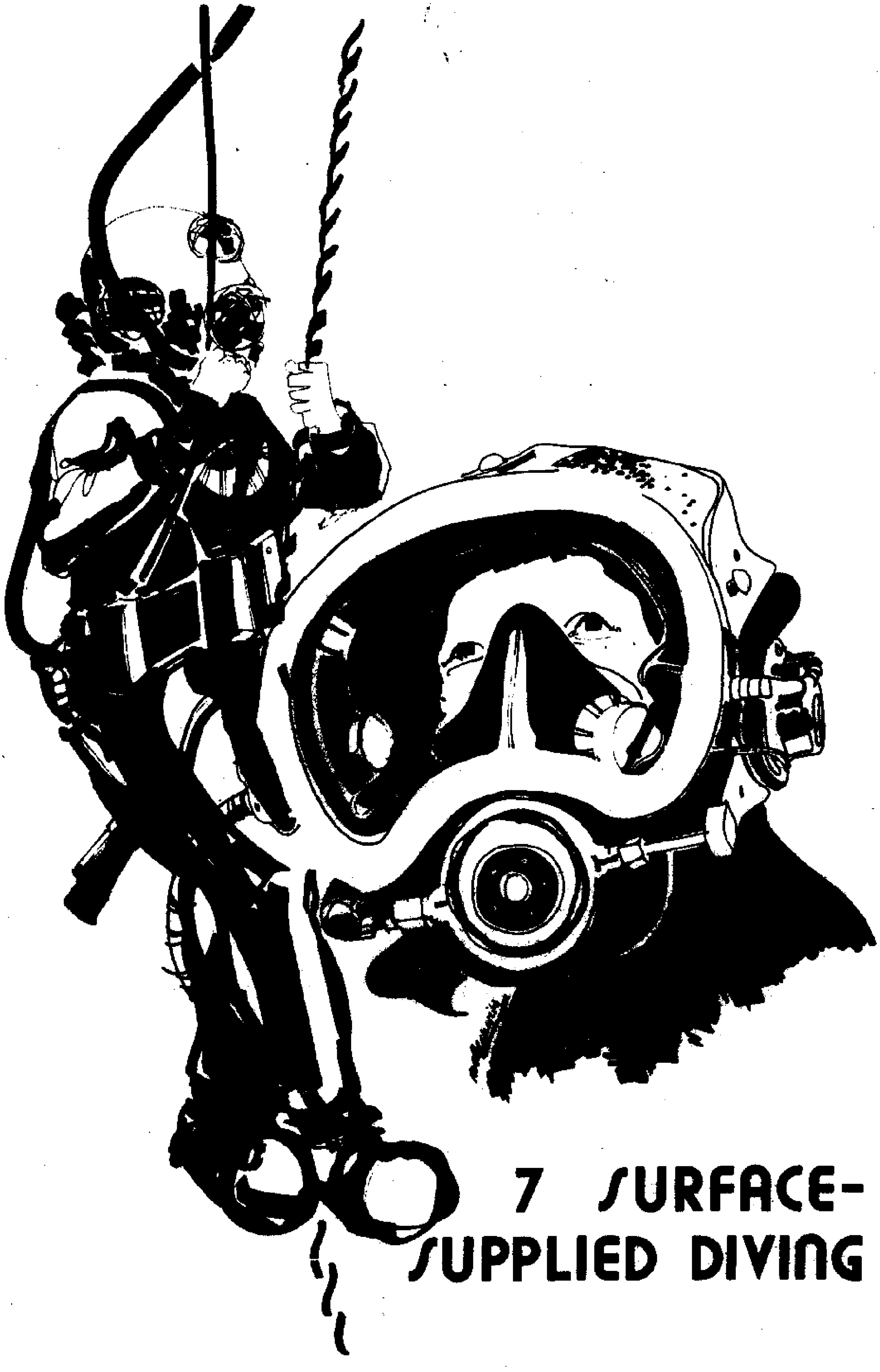


7 SURFACE-SUPPLIED DIVING

7.0 Surface-Supplied Diving

7.1 Introduction

Self-contained diving techniques have been used by research divers for two decades. Self-contained underwater breathing apparatus (SCUBA) allows the diver considerable advantages in portability, underwater mobility, and simplicity of operation. In addition, training in the use of open-circuit SCUBA is readily available for most research personnel. In order to utilize the advantages of SCUBA, the diver has sacrificed dive duration, physical (thermal) comfort, reliable communication capabilities, and safety under limited visibility conditions.

Operational efficiency has always been relatively low when using self-contained diving techniques. In addition to the limiting factors previously mentioned, SCUBA diving requires that, for safety purposes, at least two divers be used on all missions. Frequently, the mission could be as effectively accomplished by a single diver. Also, when working under limited visibility conditions (common in the lower Great Lakes), two SCUBA divers can easily become separated and offer each other little or no assistance in an emergency. In fact, SCUBA diving under zero visibility conditions actually constitutes a hazardous situation.

Recognizing inherent disadvantages and limitations imposed by the use of SCUBA diving techniques, University of Michigan scientists now employ surface-supplied diving techniques for *most* underwater research. The diver wears a free-flow/demand mask or lightweight helmet (Figure 7-1) and is connected to the surface by an umbilical hose, which consists of an air hose, hot-water hose, and communication line. Air is supplied by a compressor or high-pressure cascade system located on the support vessel. A hot-water circulating diving suit is used to maintain a high degree of thermal comfort. Heat loss is no longer a limiting factor of dive duration regardless of the water temperature. A wire-type communications system provides excellent diver-surface voice communications. Self-contained wireless-type communication systems have been used in the past; however, compared to wire-type systems, these self-contained units lack the reliability, clarity, and overall performance characteristics necessary for transmitting precise data to the scientist on the surface. Use of the wire-type system enables surface personnel to maintain *constant* communication with the

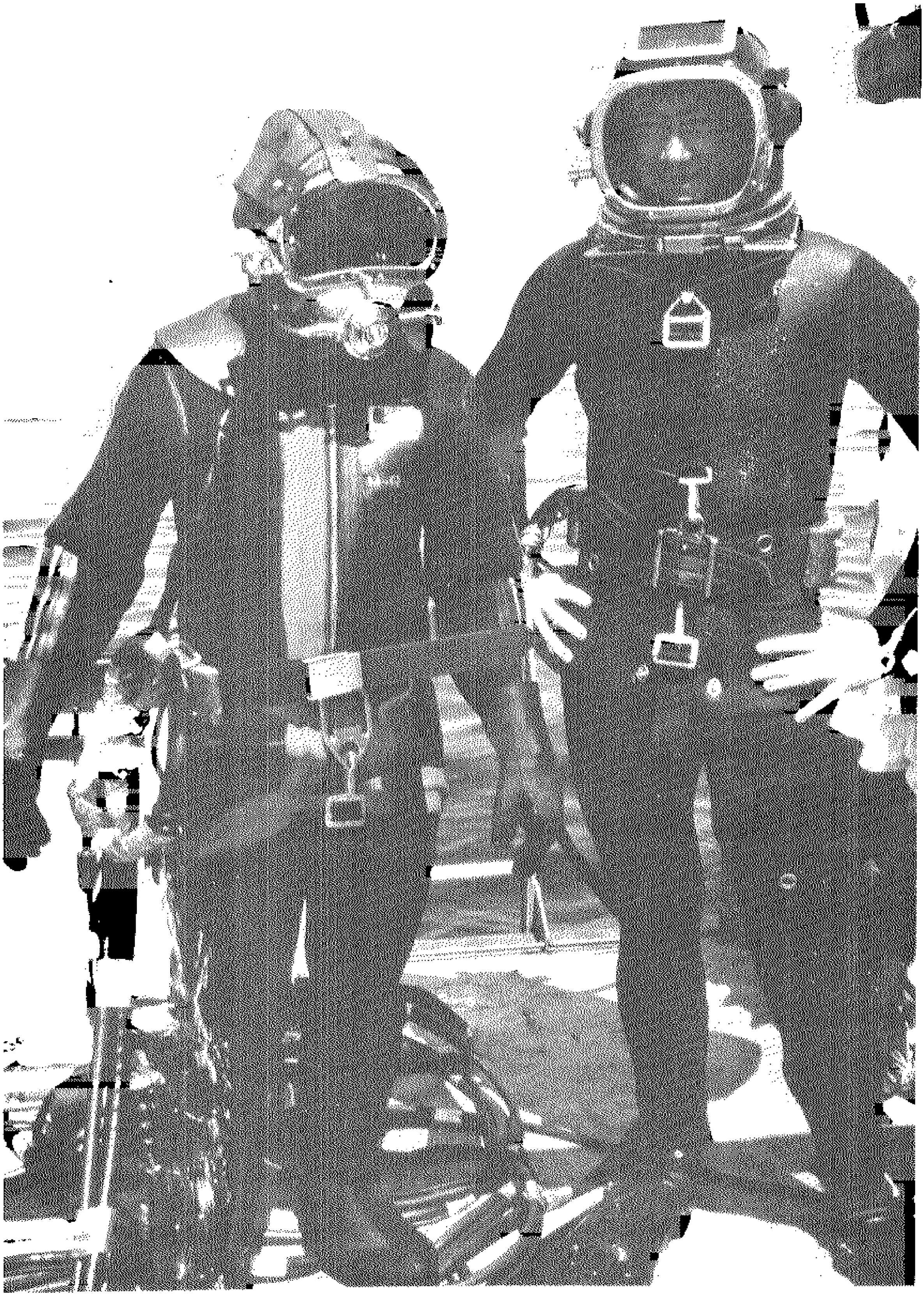


Figure 7-1. Surface-Supplied Divers Wearing Free-Flow/Demand Mask and Hot-Water Suit (Left) and Lightweight Helmet and Cold-Water Wet Suit (Right) (Photo by P. Blackburn)

diver and record all data on tape. This procedure increases by several orders of magnitude the accuracy of recording diver observations and the general safety of the diver.

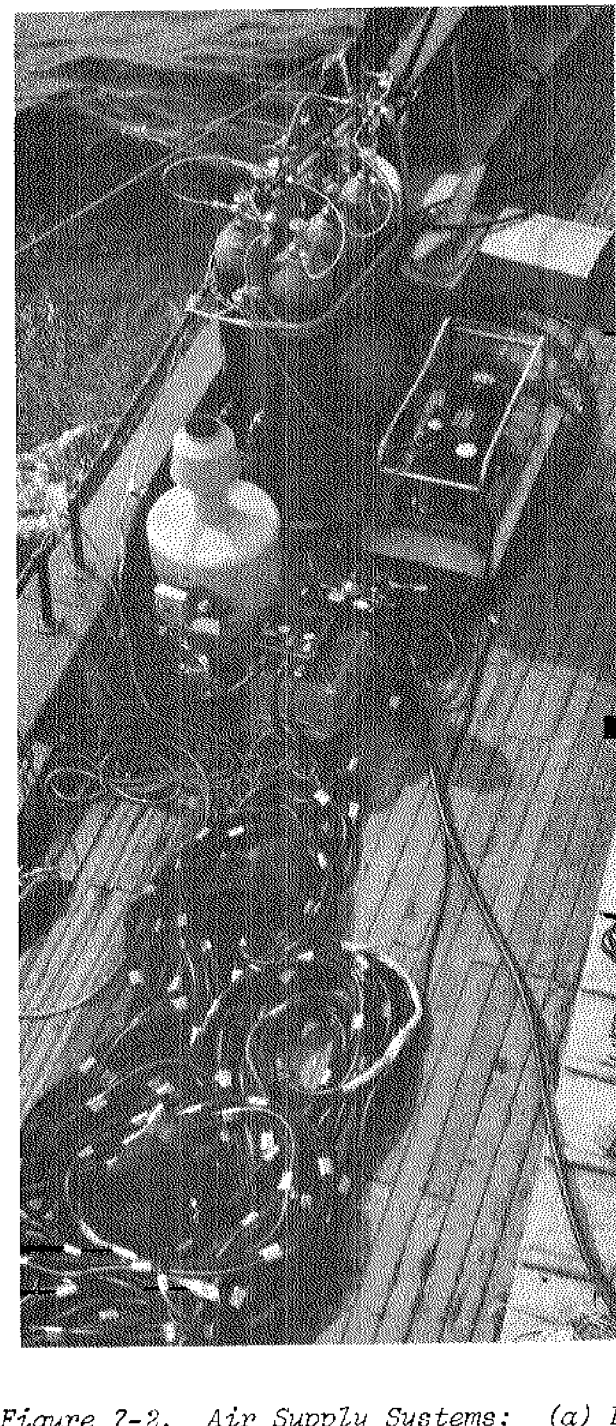
Using surface-supplied diving techniques, only one diver enters the water at a time for most missions. A tender handles the umbilical hose on deck and maintains constant communications with the diver; a stand-by diver is available for emergency assistance. Committing only one diver to the underwater mission at a time compared to the two-diver requirement for SCUBA diving increases operational efficiency by a factor of two. The virtually unlimited air supply and the degree of control for safe decompression increases dive durations for shallow and moderate depth missions. Consequently, dive timing and decompression procedures must be precise, and an on-site decompression chamber is recommended. Finally, the thermal protection provided to the divers by the open-circuit, hot-water suit system eliminates diver inefficiency and time limitations due to heat loss. Considering these factors, diver efficiency or operational capability is increased by at least a factor of four.

The diver is limited in lateral range by the length of his umbilical hose. However, for a diver wearing fins, vertical and lateral movement within this range is comparable with movement when using SCUBA. A free-flow/demand mask and lightweight helmet provide the diver with the large quantity of air required during periods of heavy exertion, thus allowing him to accomplish tasks that would be marginal or impossible when using SCUBA.

The application of modern surface-supplied diving techniques to research operations is a revolutionary advancement in underwater research. Diving mission capabilities are greatly extended and higher standards of safety are maintained.

7.2 Surface Air-Supply System

The most important consideration in surface-supplied diving is that of providing the diver with an adequate breathing gas supply. Air supplied from a compressor driven by an internal-combustion engine or from an air cascade system (Figure 7-2) is used as a breathing medium for shallow- to moderate-depth diving operations. The air supply system must be capable of delivering the volume and pressure required by the diver at working depth.



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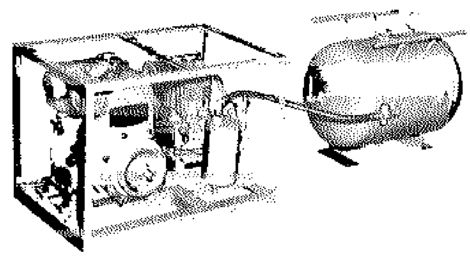

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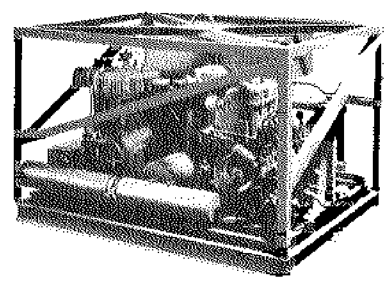

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Figure 7-2. Air Supply Systems: (a) Bank of 240 ft^3 *high-Pressure Air Cylinders, High-Pressure Air Compressor, Hot-Water Heater, and Umbilical Hose on Deck of R/V* Inland Seas; *(b) Compact Low-Pressure Air Compressor and Separate Air Receiving Tank; (c) High Capacity Diesel-Engine-Driven Low-Pressure Compressor, 72 ft*^{3}*/min, 250 lb/in*^{2}*, size: 48 x 64 x 44 in., weight: 1080 lb. (Photo a by R. Anderson; Photos b and c by Bolstad Engineering and Manufacturing)*

For free-flow, lightweight helmet and mask ventilation, a minimum air supply of 1.5 ft^3/min (measured at the absolute pressure of the diver's depth) is adequate only for light work. Ideally, the volume of air available to the diver should be at least 4.5 ft^3/min at depth. When using a free-flow, lightweight helmet or mask, a hose pressure of at least 50 lb/in^2 over ambient is required for dives to less than 120 ft and 100 lb/in^2 over ambient is required for depths exceeding 120 ft. For free-flow/demand masks, a delivery volume of at least 3 ft^3/min at depth should be available and a hose pressure of 100 lb/in^2 over ambient is recommended. The system must also be capable of supporting a stand-by diver unless a separate system is provided for this purpose. The system must be equipped with a volume tank and/or secondary air cylinder sufficient to provide at least 5 min of air at working depth in the event of primary failure.

7.2.1 Sources of Compressed Air

The common sources of compressed air are

a. High-pressure air cylinders, and

b. Low-pressure compressors powered by electric motors or internal-combustion engines.

A four-to-twelve 240- or 300-ft^3 cylinder high-pressure air cascade system is satisfactory for diving with a free-flow/demand mask. High-pressure air cascade units are used extensively in University of Michigan diving operations. Generally, six 240- or 300-ft^3 cylinders are mounted on a cradle fitted with a manifold system. Several 6-cylinder cradles may be used for extended operations. A two- or four-cylinder unit is used for small boat operations (usually limited dive durations and/or shallow water). The high-pressure cylinders are charged using a high-pressure air compressor driven by an electric motor (Mako Products, Model K1405, 8 ft^3/min, 3200 lb/in^2, 850 rpm). This system provides a sufficient air supply and enables the group to operate without the excessive noise of an air compressor's motor during diving operations. This enhances communications considerably and provides more pleasant conditions for surface personnel. The divers consider this arrangement safer and more dependable than most systems previously investigated. On large operations, one cradle unit can be recharged while others are in operation. In addition, the same system may be used to support SCUBA diving operations. High-pressure gas reduction regulators (Victor model VTS 700E, outlet pressure to 250 lb/in^2, flow capacity to 4000 ft^3/hr) are used to regulate delivery air pressure. A gas control board has now been designed to regulate primary and secondary (emergency) air for two divers.

A low-pressure air compressor is generally used for surface-supplied diving missions. The capacity requirements of the compressor system will depend on the type of diving apparatus, diving depth, exertion level, and auxiliary equipment requirements. Flow rate and diving station manifold pressure may be calculated by formula or read directly from a graph given by Hansen (1972) (Figure 7-3). The rated pressure of the compressor must exceed the pressure calculated due to losses in the compressed air piping system. Also, normally the compressor does not operate continuously at the rated pressure, but is controlled to unload or stop at this pressure.

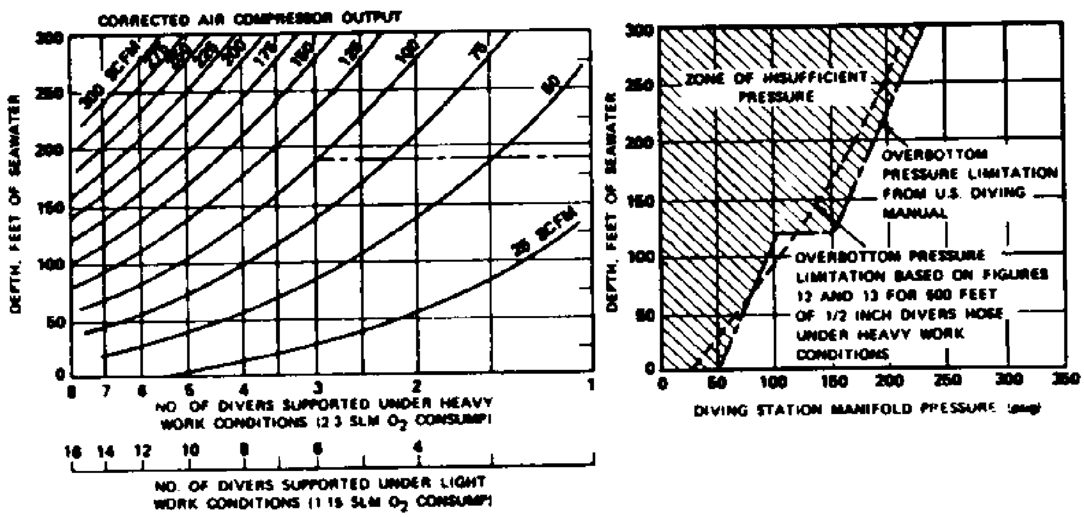


Figure 7-3. Flow Rate and Diving Station Manifold Pressure

Additional considerations must be made for air requirements of stand-by divers and recompression chamber operations. Based on data given by Hansen (1972), the US Navy requires a chamber ventilation rate (two patients and one tender in chamber) of 140.7 ft^3/min at the 60-ft oxygen stop. Total air requirements for treatment of air embolism or decompression sickness may range from 13, 754 to 46, 625 ft^3 (Table 7-1).

VENTILATION AIR REQUIREMENTS FOR TREATMENT
TABLES 1–6A (REF. 1)
(TWO PATIENTS AND ONE TENDER IN CHAMBER)

TREATMENT TABLES 1–4

DEPTH OF STOP (FSW)	VENT RATE (SCFM) AIR STOP	VENT RATE (SCFM) O_2 STOP	VENTILATION AIR REQUIRED AT STOP (SCF) — TREATMENT TABLE 1	1A	2	2A	3(O$_2$)	3(AIR)	4(O$_2$)	4(AIR)
165	47.9				1437	1437	1437	1437	5749	5749
140	41.9				503	503	503	503	1256	1256
120	37				444	444	444	444	1111	1111
100	32.2		966	966	386	386	386	386	966	966
80	27.3		328	328	328	328	328	328	821	821
60	22.8	140.7	4221	675	4221	676	4221	676	8104	8104
50	20.1	126.6	3767	603	3768	603	3768	603	7234	7234
40	17.7	110.5	3315	530	3314	530	3314	530	6063	6063
30	15.3	96.4	↓	916	5721	1831	10884	10884	15790	10885
20	12.8	80.2	↓	770	↓	1540	1541	1541	5685	1540
			401		383					
10	10.4	65	↓	1250	↓	2501	1250	1250	4532	1250
PRESSURIZATION	570		756	756	1247	1247	1247	1247	1247	1247
TOTAL FOR TREATMENT			13754	8794	21732	17026	29423	19879	58757	46625

TREATMENT TABLES 5–6A

DEPTH OF STOP (FSW)	VENT RATE (SCFM) AIR STOP	VENT RATE (SCFM) O_2 STOP	VENT AIR USED AT STOP — TREATMENT TABLE 5	5A	6	6A
165	47.9			719		1437
				138		138
60	22.5	140.7	5741	5741	8780	8780
			3640	3640	3641	3640
30	15.3	96.4	2080	2080	11900	11900
			2180	2180	2180	2180
0			↓	↓	↓	↓
PRESSURIZATION		570	453	1247	453	1247
TOTAL FOR TREATMENT			13974	15625	26854	29723

Table 7-1. Ventilation Air Requirements for Treatment of Air Embolism or Decompression Sickness

All surface-supplied diving compressors must be equipped with a large-capacity, low-pressure accumulator or air receiver tank. This tank aids in maintaining delivery pressure at a constant level and contains an air supply which is available to the diver in the event of compressor failure. The receiver is fitted with a safety valve to prevent overpressurization and a line to the diver's air-control valve and gauge.

Most heavy compressors are powered by diesel engines. Diesel-powered compressors reduce fire hazard and are more versatile than electric-powered compressors. All diving air compressors should be protected by a substantial external frame or cage and mounted on skids. A hoisting bail should be fitted to the frame to facilitate handling.

The delivery pressure and free-air volume will depend on the make and model of compressor. A lightweight compressor may have, for example, a maximum delivery pressure of 100 lb/in^2 and a 16 ft^3/min displacement. Heavy-duty compressors have pressure ratings of 200-350 lb/in^2 and 50-125 ft^3/min displacements. When calculating delivery volume at various pressures, consult the manufacturer's specifications. A compressor that delivers 107 ft^3/min at atmospheric pressure will deliver only approximately 85 ft^3/min at 125 lb/in^2. For additional information and specifications on compressor for divers, consult companies that specialize in air compressors for diving. One such firm is Bolstad Sales and Service Corporation, 401 Centre Street, San Pedro, California.

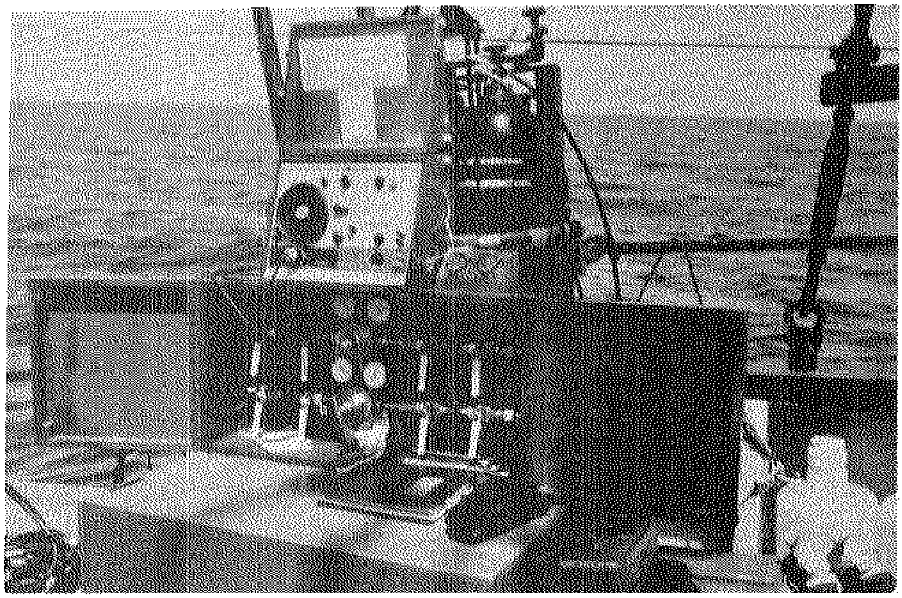
7.2.2 Air Control System

A pressure reduction regulator system is required to reduce the high cylinder pressure to working pressure. For shallow-water work, a single one- or two-stage gas reduction regulator (4000 ft^3/min or higher and 250 lb/in^2 outlet pressure) with a high flow capacity is satisfactory. Two or more cylinders are connected in series and the regulator is attached to the manifold. When using a single regulator system, the diver should be equipped with a self-contained emergency air supply and/or a low-pressure volume tank on the surface.

For deep water, working in pipelines, etc., a more elaborate air regulator system is recommended. Air control systems are not standardized; they are usually designed to the specifications of individual divers or diving firms. The system which I designed for the University of Michigan diving operations includes two regulators, two diver outlets, and connections for primary and emergency air supplies (Figure 7-4). Either regulator may be supplied by air from the primary or emergency air source at a given time. In the event of a regulator malfunction, the supervisor or tender may immediately activate ball valves to isolate the faulty regulator and switch the diver to the stand-by regulator. Furthermore, in the event of primary air supply failure (e.g., line rupture), the emergency air supply may be activated and the primary system isolated for repair. Even with the redundancy in the air control system, it is recommended that divers be equipped with self-contained emergency air supplies.

7.3 Free-Flow/Demand Mask

The free-flow/demand mask (Figure 7-5) is designed primarily for use with an umbilical hose, which supplies breathing gas from the surface, an underwater habitat, or a personnel transfer capsule (submersible decompression chamber). The US Diver Company Model KMB-8 diver's band mask and General Aquadyne Model



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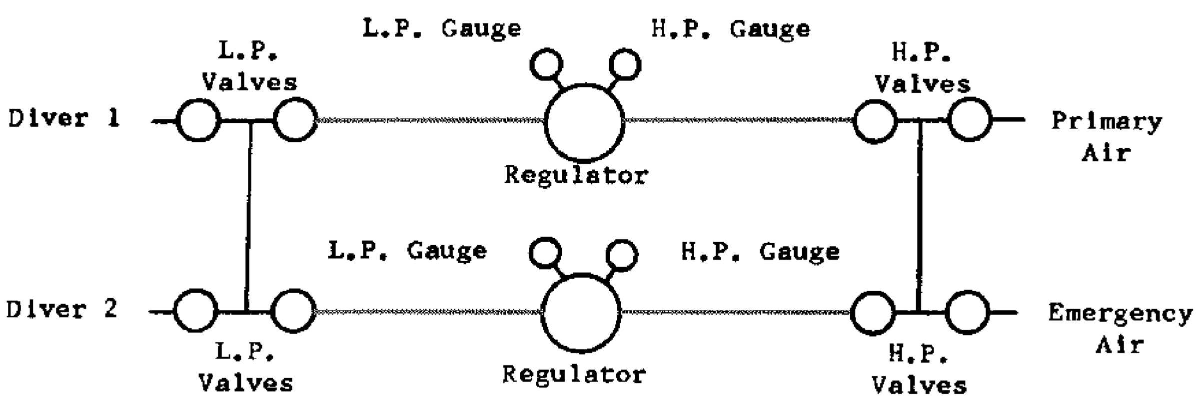

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Figure 7-4. Air Control Panel: (a) Air Control Panel Used by University of Michigan Divers; (b) Schematic Diagram (Photo by Somers)

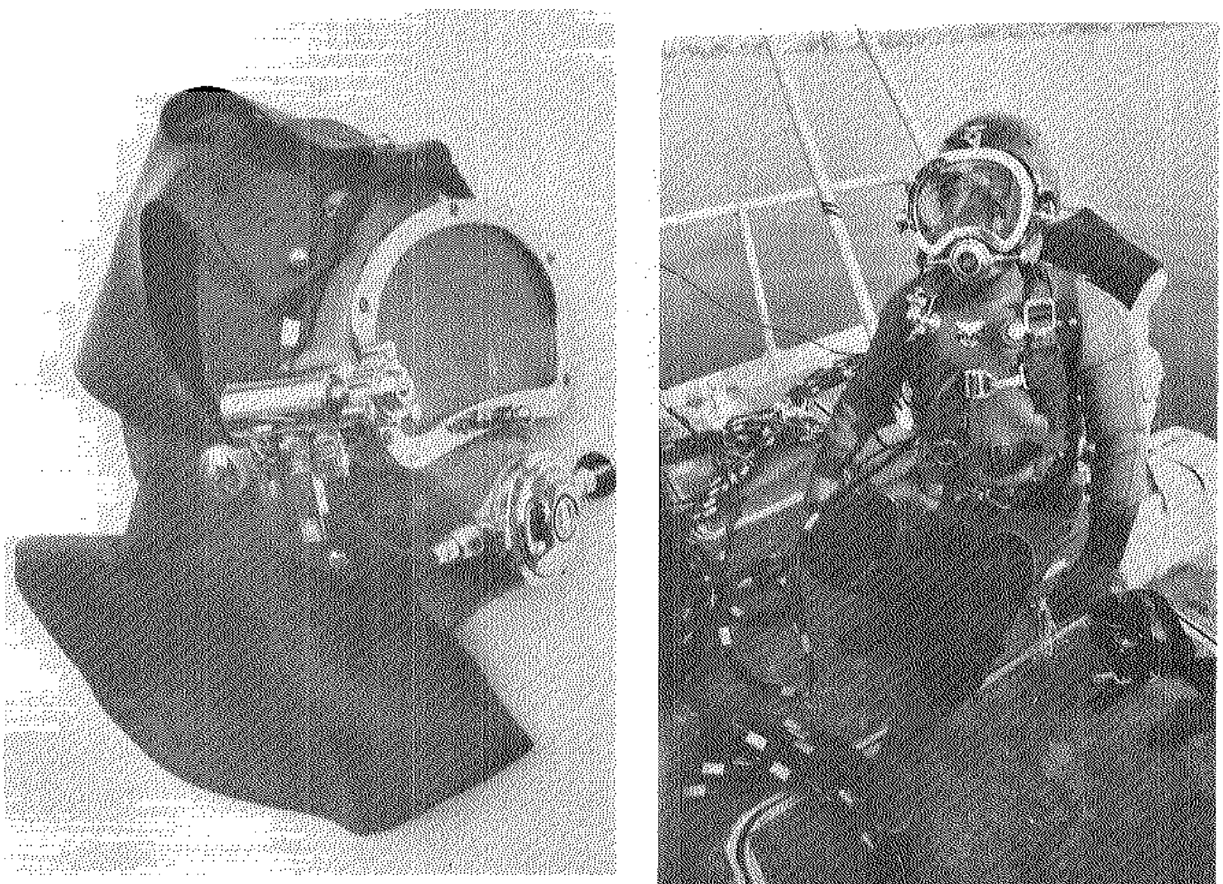

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Figure 7-5. Free-Flow/Demand Mask: (a) KMB-8 Band Mask; (b) Diver Equipped with Aquadyne Mask and Variable-Volume Suit (UNISUIT) (Photo by Somers)

DM-4 diving mask are used by University of Michigan divers. The KMB-8 mask is fabricated of noncorrosive, rigid fiber glass and may be used with air or mixed gas. The face port is 1/4-in. acrylic plastic. The free-flow system is necessary to provide adequate ventilation for a diver doing heavy work underwater. A free-flow valve allows the diver an adjustable-flow off-on supply to the interior of the mask through the muffler-deflector. In addition to supplying the diver with a steady flow of breathing gas, the deflector directs gas across the viewing lens, thus clearing any fogging that may occur. When the umbilical hose is pressurized with the breathing media, a demand regulator is pressure-loaded at all times. The regulator provides a "demand" breathing system, similar to standard open-circuit SCUBA, which is adjustable for gas supplies from 60-180 lb/in^2 over ambient pressure. The demand system is used under light to moderate working conditions to economize on gas volume requirements and to enhance communications.

A nose blocking device is incorporated into the mask to facilitate sinus and middle-ear equalization. An oral-nasal mask assembly is used to reduce dead air space and eliminate the possibility of a dead air space CO_2 build-up. The main exhaust valve, located at the bottom of the fiber-glass body, provides automatic water purging whenever necessary. The integrated, expansion-type, rubber, face seal and cold-water, rubber, hood assembly are attached to the mask body by a metal retainer band. Two pockets in the hood contain the communications earphones, and the microphone is located in the oral-nasal mask. A hole-type head harness ("Spider") secures the mask to the diver's head. The umbilical hose is attached to a nonreturn valve on the mask to prevent loss of pressure in the event of a hose rupture or air supply malfunction. Fittings are oxygen type, 9/16 in., 18, male. The mask is designed with a fitting for the attachment of a hose from a small high-pressure cylinder carried on the diver's back. The emergency air supply system ("bailout") may be activated immediately by the diver and is recommended for all dives in excess of 60 ft.

The General Aquadyne Model DM-4 diving mask is similar to the KMB-8 band mask in principle of operation and materials. The demand regulator is designed to function through a supply pressure range of 50-200 lb/in^2 over ambient. Two exhaust value assemblies are bonded into the lower mask body, one on each side, and function automatically by differential pressure between the mask interior and ambient water pressure. The valves are neoprene rubber mushroom type. Since this mask does not have a hood assembly, an earphone, contained in a watertight housing, is mounted on a boom extending over the diver's left ear. The earphone housing is pressure compensated from within the mask by an equalizer tube, which also serves as a conduit for the earphone wiring.

The face seal is fabricated from open-cell polyfoam with a neoprene cover perforated to permit pressure equalization of the polyfoam at depth. The face seal assembly is bonded to the mask with neoprene rubber cement.

Probably the most significant difference between the KMB-8 and DM-4 masks is the emergercy gas supply activating system. Instead of incorporating the switch-over valve in the side valve of the mask (as the KMB-8), the DM-4 features a separate manifold block to serve as the distribution point for both the primary and emergency air sources. Consequently, only one supply hose is attached to the side valve of the mask. The block is secured to the diver's harness or a separate belt near waist level on the right side. The block contains three ports: one primary gas inlet, one emergency supply inlet, and a common gas outlet to the mask. A cartridge check valve incorporated into the primary air passage and retained by the inlet fitting prevents loss of emergency gas in the event of primary gas hose failure. A shutoff valve on the manifold isolates the emergency gas supply from the common outlet until activated by the diver. A 400 lb/in^2 working pressure hose from the common outlet port and terminating with a standard oxygen fitting (9/16-in., 18, female swivel nut) on the free end for connecting to the mask is standard. The emergency air inlet port is provided with a hose for connection to a standard first-stage regulator (fitting: 3/8-in., 24, male, O-ring seal.)

Both masks may be used with optional fiber-glass head protectors. The KMB-8 band mask head protector is secured to the mask head harness. It rests directly on the diver's head and is padded with closed-cell foam rubber for shock absorption. The head protector for use with the DM-4 mask is free from contact with the diver's head. It attaches to the mask head harness post and is secured with elastic retainers.

7.3.1 Dive Preparation Procedures

The following procedures are recommended when preparing the *mask* for diving:

1. Inspect the mask for any damage or loose fittings. On the KMB-8 mask check to ensure that the hood retaining band is properly secured.

2. Open free-flow valve, blow through the check valve, and then suck back to ensure that the check (non-return) valve is functioning.

3. Check free-flow valve and regulator adjustment for free movement.

4. Check exhaust valves to ensure that they are properly seated and free from foreign matter.

5. Connect communications wire and test communications.

6. Purge gas supply hose to ensure that it is free from foreign matter.

7. When using the Aquadyne emergency manifold block, attach to gas supply hose and purge prior to attachment to mask.

8. Verify that the emergency gas cylinder is filled to capacity, attach regulator, and connect to manifold block (DM-4) or mask (KMB-8).

9. Prior to connecting the primary gas supply hose, open the emergency cylinder valve and activate emergency system to verify proper function. Check for leaks and close emergency system valve.

10. Connect primary gas supply hose and verify free flow and demand system operation. Adjust the demand regulator to slight free flow and then close until free flow stops. Readjustments may be required at depth.

11. Apply a thin film of antifogging solution to the interior of the face port to prevent fogging during the dive. Liquid dishwashing soap is highly satisfactory.

12. Place the mask on and test both breathing systems.

13. Secure the head harness as low as possible on the neck so that pressure is put on the base of the

skull by the lower legs of the harness. The amount of tension will vary with individual preference.

14. Secure the umbilical hose to the diver's harness or belt.

7.3.2 Purging a Flooded Mask

A partially or completely flooded mask can be quickly purged by placing the exhaust valve in a downward position and opening the free-flow valve or depressing the manual purge button on the demand regulator.

7.3.3 Emergency Ascent

An emergency gas supply or "bailout" unit (Figure 7-6) is a great asset in any type of diving, especially when working at depths in excess of 60 ft, in tunnels, or where direct ascent is prohibited. Upon failure of the primary gas supply, the emergency gas valve is opened and the diver proceeds directly to the surface or first decompression stop. The free-flow valve should be closed and the demand circuit used to conserve gas. Should the diver's hose be fouled to the degree of preventing ascent and the primary gas supply is inoperative, the diver should alert the surface crew of his situation and notify them that he is cutting the umbilical hose to make an emergency ascent.

Should gas failure occur when diving without self-contained emergency supply, the diver may drop his weight belt and ascend without removing the mask (exhaling throughout the ascent to prevent air embolism). In the event that the diver's hose is fouled, preventing him from surfacing with the mask on, the weight belt and harness (or harness attachment) should be released. The diver then removes the mask by grasping the main body and pulling the mask forward, up, and over the head.

7.3.4 Postdive Procedures and Preventive Maintenance

Each diver must establish his own standards for care of a mask. The use of the mask in fresh water will require a time table for maintenance procedures different from that when the mask is used in sea water. The type of underwater activity will also determine maintenance requirements.

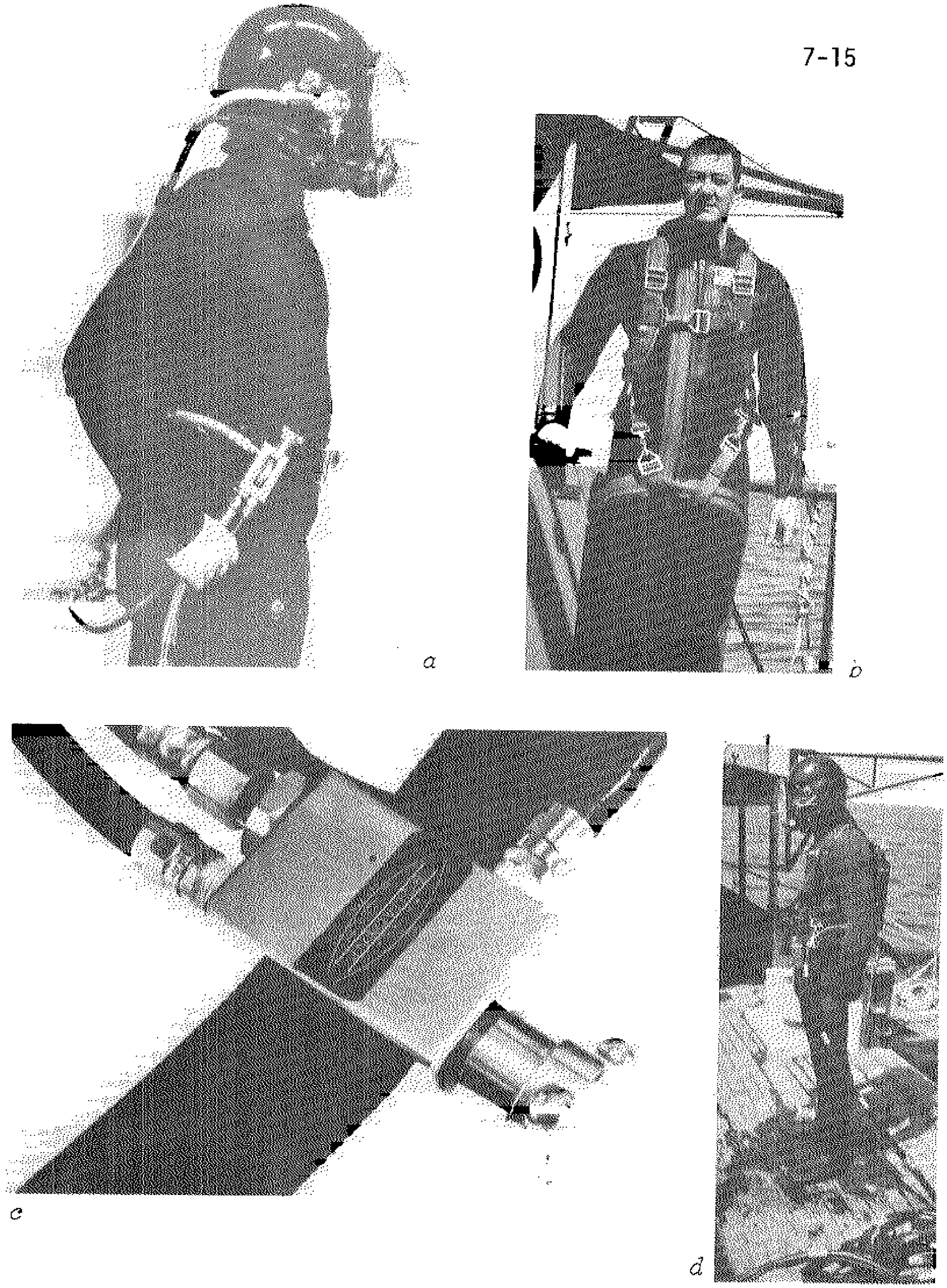


Figure 7-6. Surface-Supplied Diving Components: (a) Diver Equipped with Free-Flow/Demand Mask, Head Protector, and Emergency Gas Supply Unit; (b) Diver in Hot-Water Suit and Modified Parachute Body Harness; (c) Emergency Gas Supply Manifold; (d) Diver Equipped with Free-Flow/Demand Mask, Head Protector, Emergency Gas Supply Unit, UNISUIT, and "Gulf"-Type Body Harness (Photos a and c, Courtesy of Aquadyne; b and d, by W. Michaels)

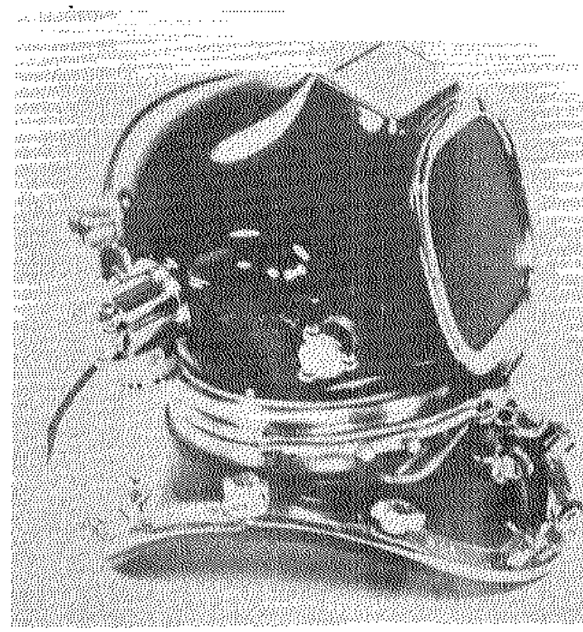
When diving in sea water, the exterior of the mask should be rinsed in fresh water following each dive. Care must be taken not to flood the microphones since they are not waterproof. The interior of the mask should be wiped clean with a cloth or sponge. A damp sponge may be used to clean the interior. An alcohol solution is useful for cleaning and disinfecting the oral-nasal mask. The interior should be completely dry when the mask is stored, even overnight. The DM-4 mask should be placed in a face-down position to allow water to drain from the face seal.

The KMB-8 mask requires additional maintenance procedures. When fitted with a cold-water hood, the interior of this mask is difficult to clean and dry unless the hood is removed. With the hood removed, turn it inside out and squeeze water out of the open-cell foam face seal. Dry interior of hood and mask completely before reassembling. Installation of a zipper in the back of the hood will simplify maintenance since the hood will not have to be completely removed as frequently. Monthly maintenance (or between diving operations) and repair should be in accordance with procedures given in the manufacturer's manual supplied with each mask.

7.4 Lightweight Helmets

A number of lightweight, free-flow, diving helmets (Figure 7-7) have been designed and manufactured in recent years. Some manufacturers have constructed helmets of traditional spun copper with emphasis on indestructibility, while others use fiber glass with emphasis on comfort, lightweightness, and maneuverability. In general, modern lightweight helmets feature streamlined design, standardized interchangeable fittings, improved valves, unbreakable faceplates, better ventilation (low CO_2 build-up), improved visibility, better communications, versatility with any type of dress, bailout capability, and simplicity of use and maintenance. Modern lightweight helmet design criteria are discussed by Jones (1970) and a brief description of the major helmets is given in the publication *Undercurrents* (July 1968; October 1969) and by Zinkowski (1971). A description of the General Aquadyne helmet, currently used at The University of Michigan, is given in the next section.

a



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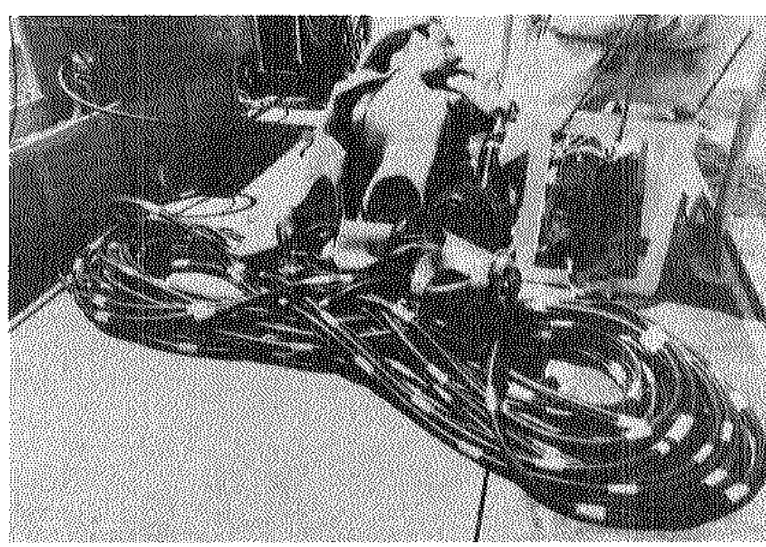

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Figure 7-7. Surface-Supplied Diving Helmet and Umbilical Hose: (a) Diver Equipped with Lightweight Helmet and Variable-Volume Suit; (b) Lightweight Helmet with Breastplate for Use with Navy-Type Deep-Sea Dress; (c) Air Hose and Communication Line Coiled on Ship's Deck (Photos by Somers)

7.4.1 General Aquadyne Lightweight Helmet

The General Aquadyne lightweight helmet is constructed of noncorrosive, reinforced polyester fiber glass. Top and front viewports, made from 1/4-in. and 3/8-in. polycarbonate (Lexan), are shatterproof and offer exceptionally high optical properties. The streamlined shape offers minimum resistance to movement and current. A watertight, adjustable exhaust valve allows the diver to work in any position. The exhaust valve may be manually controlled outside the helmet or activated internally by pushing a button with the head. Air flow is regulated by a conveniently located control valve on the side of the helmet.

The helmet attaches to a stainless-steel neckring and secures with a locking mechanism. This neckring enables the diver to dress-in unassisted in darkness if necessary. The neckring may be attached to a standard dry suit, constant-volume dry suit, or a foamed-neoprene neckseal. By using the neckseal, the diver can work in a swimsuit, wet suit, coveralls, variable-volume dry suit with attached hood, or hot-water suit. A light adjustable belt provided with the helmet is used to secure the neckring to the diver. The weight belt is worn over this adjustment belt. A breastplate is available to allow the use of a conventional deep-sea dress with the helmet (Figure 7-7).

7.4.2 Dive Preparation Procedures

The following procedures are recommended when preparing the *helmet* for diving:

1. Inspect the helmet for any damage or loose fittings.

2. Open free-flow valve, blow through the check valve, and then suck back to ensure that the check (nonreturn) valve is functioning. Another method of ensuring that the internal nonreturn valve is operating satisfactorily is to close the free-flow valve, connect an air supply to the helmet, and flow some air into the helmet. Without opening the free-flow valve, bleed and remove the air supply line. Submerge the helmet air hose connection in water; if no bubbles emerge, the valve is functioning properly.

3. Check free-flow and exhaust valve for free movement.

4. Purge gas supply hose to ensure that it is free from foreign matter.

5. When using the Aquadyne emergency manifold, attach to the gas supply hose and purge prior to attachment to helmet. Verify that the emergency gas cylinder is filled to capacity and that the system is working properly.

6. Connect primary gas supply hose and verify free-flow system operation.

7. Connect communications wire and test communications.

8. Apply a thin film of antifogging solution to the interior of the face port to prevent fogging during the dive.

7.4.3 Dress-in Procedures

1. Don the diving suit and harness and prepare all other equipment.

2. Fasten the adjustment belt around the waist with the hose anchor "D"-ring at the left and up. Adjust the crotch and waist strap and slide helmet anchor to center front.

3. Connect the crotch strap snap to the bottom of the helmet anchor and adjust until comfortably snug.

4. Remove the helmet from the neckring and close the latching system.

5. Slide the neckring over the head with the latching system in front.

6. Snap the front and back neckring adjusting straps to the top of the brass anchor and center back "D"-ring, respectively.

7. Adjust the back strap so that the back of the neckring is slightly lower than the front.

8. Take up slack in the front strap. Don weight belt.

9. Open the latching system on the neckring and spread the clamps.

10. Activate a slight flow of air into the helmet.

11. Place the helmet over the head and lock it into the bayonet studs located in the neckring on each side by rotating the helmet to the diver's left.

12. With the helmet completely engaged, close the clamps and secure.

13. Verify the lock.

14. Secure the umbilical hose to the harness.

Final adjustment of the helmet's position is accomplished in the water. If the diver is dressed as instructed above, all adjustments may be accomplished in the water using the front strap. When adjusted, the neckring should be perpendicular to the diver's neck. There should be little pressure on the diver's shoulders and his head should be free to move. Air flow and exhaust is adjusted to the demands of the individual diver.

7.5 Umbilical Hose

The umbilical hose for surface-supplied, lightweight helmet and free-flow/demand mask consists of a gas supply hose and wire for communications (Figure 7-7). Usually a small hose for a pneumofathometer is included and, depending on mission requirements, a hot-water supply hose. Separate lifelines are no longer deemed necessary by most authorities since other components of the umbilical hose have high breaking strength ratings. Umbilical hoses are generally assembled in lengths based on specifications of the diver or diving group. Standard assemblies used by the University of Michigan are 100-, 150-, or 250-ft lengths; fittings are standardized and several of these may be joined to provide longer umbilical systems if necessary. A standard length for commercial diving umbilical hoses appears to be 300 ft although most are made to the specifications of the diving firm.

7.5.1 Gas Supply Hose

Usually a 3/8-in. inside diameter, synthetic rubber, braid-reinforced, heavy-duty hose is used for the diver's gas supply. The hose must have a working pressure of 200 lb/in^2 or more. The outer cover must be durable for resistance to abrasion, weathering, oil, and snag damage; a nontoxic inside tube should be impervious to breathing gases. Hoses must be flexible, kink resistant, and easy to handle. Low-quality, inexpensive air hose should be avoided. Although a hose may have a sufficient pressure rating, it may shrink considerably when pressurized. A reduction in gas supply hose length will cause "looping" of the other members of the umbilical assembly between tapings. This increases the potential of snagging the umbilical hose during a dive. Consequently, to avoid problems, the percent of shrinkage must be determined prior to purchase and the umbilical assembly must be taped while the hose is pressurized. Length change under 100-150 lb/in^2 pressure should not exceed 2 percent.

A satisfactory hose commonly used for diving is synthetic rubber hydraulic hose that meets or exceeds requirements SAE 100 R-3. An example is Gates 19 HB hydraulic hose (2-fiber braid, SAE 100 R-3, 3/8-in. ID, 3/4-in. OD, working pressure of 1125 lb/in^2). Standard brass reuseable oxygen fitting (9/16-in., 18, female) are recommended. All University of Michigan hoses are equipped with female fittings at both ends; two-hose assemblies may be coupled with a double male fitting. This standardization has proven satisfactory and enhances equipment handling procedures.

Periodically, the gas supply hose should be visually inspected and pressure tested. When the air supply hose (SAE 100 R-3 or equivalent) is three years old, a 350-lb/in^2 air pressure test with a concurrent elongation load of 250 lb on the couplings held for a period of 1 min is recommended. The hose should be tested every six months thereafter and hoses more than five years old should not be used for diving.

7.5.2 Communications Wire

The communications wire must be durable enough to prevent parting due to strain on the umbilical assembly, and have an outer jacket that is waterproof and oil and abrasion resistant. A two, three, or four size 16 or 18 conductor shield wire with a neoprene outer jacket is satisfactory. Although only two conductors are in service at one time, the extra conductors may be used for rapid field repairs in the event of one of the conductors breaking while in service. The wire-braid shielding adds considerable strength to the umbilical assembly. For example, spiral 4 communications line with four #18 plastic-coated conductors embedded in a vinyl filler surrounded by stainless-steel wire braid and synthetic cover has a breaking strength rating in excess of 1460 lb.

The wire is fitted with connectors compatible with those on the mask or helmet. Four conductor, waterproof, Marsh-Marine "Quick Connectors" are highly satisfactory. These connectors are of a socket-type configuration. When joined together, the four electrical pin connections are established and a watertight seal is formed, insulating the wire from the surrounding sea water. Many masks and helmets are equipped with post binders instead of socket-type connectors or as a backup. The conductor wires may be attached directly to these terminals; however, the quality of communications is lowered.

7.5.3 "Kluge" or "Pneumo" Hose

The "Kluge" hose is a small hose that is open at the diver's end and connected to an air source and pneumofathometer at the surface. The pneumofathometer is a gauge which indicates the depth and gauge pressure at which the diver is working. This is the most accurate and reliable method of determining the diver's depth (providing that the pneumofathometer gauge is protected from abuse and calibrated periodically). The hose should be lightweight, small, flexible, and durable. Although the open tube is not subjected to high pressure, it should have a working pressure capacity of 200-250 lb/in^2. Lightweight air hose (.25-in. ID), extruded seamless nylon tubing (.17-in. ID, .25-in. OD, 250 lb/in^2 maximum working pressure), or thermoplastic tubing with external open polyester braid (.25-in. ID, .456-in. OD, 250 lb/in^2 maximum working pressure) have been found satisfactory. Standard oxygen fittings are recommended.

To determine the diver's depth, air (gas) is introduced into the "Kluge" hose at the surface, thus forcing the water out at the diver's end. When the hose is clear of water, excess air escapes. The gauge connected to the hose on the surface indicates the pressure required to clear the hose of water and the diver's depth.

7.5.4 Hot-Water Supply Hose

A 1/2-in. inside diameter, insulated hose is used to supply hot water to the diver's suit. The hose is equipped with a quickdisconnect, female fitting which is compatible with the diving suit manifold.

7.5.5 Assembly of Umbilical Hose

The various components of the umbilical hose are assembled and taped at approximately 1-ft intervals with black, plastic electrician's tape or 2-in. wide, polyethylene cloth, laminated tape (duct tape). The 2-in. duct tape is recommended. Prior to taping, the various components are laid out adjacent to each other and inspected for damage or abnormalities. The gas supply hose is plugged at one end and pressurized to working pressure (generally 120-200 lb/in^2, depending on depth) to ensure that the shrinkage factor will not cause "looping" when the umbilical hose is in use. Divers have personal preferences with regard to the configuration of the assembly at the mask or helmet end. When assembling the umbilical hose, take into account the length of mask or helmet hose whip (if used) and communications whip and the hot-water hose connection location. Generally the communications wire is longer than the rest of the assembly at the diver's end. This provides an extra length of wire in the event that repairs must be accomplished at the diver's end. The excess is looped around the umbilical hose and secured with tape. If there is a possibility that several assembly lengths may be joined to provide a longer umbilical assembly, all lengths must be carefully measured and assembled for compatibility. It is best to start taping at the diver's end and work toward the surface end.

A swivel snap shackle or special air hose clamp is secured to the umbilical assembly to facilitate attachment to the diver's harness and prevent pull on the helmet and mask when in use. The shackle may be tightly secured to the umbilical assembly with several wraps of 1/4-in. nylon line. Attachment location will depend on the harness assembly and diver's personal preference.

7.5.6 Use and Storage of Umbilical Hose

After the umbilical hose is assembled, it should be stored and transported with protection provided for hose and communications fittings. The hose ends should be capped with plastic protectors or taped closed to keep out foreign matter and to protect threaded fittings. The umbilical hose may be coiled on take-up reel assemblies, "figure-eighted," or coiled on deck with one loop over and one loop under. Incorrect coiling, all in the same direction, will cause twist and, subsequently, handling problems. The tender should check the umbilical assembly at the end of each dive to ensure that there are no twists. The coil should be secured with a number of ties to prevent uncoiling during handling. Placing the umbilical assembly in a large canvas bag or wrapping it in a tarp will prevent damage during transport.

7.6 Hardwire Communications System

The underwater telephone or hardwire system (Figure 7-8) used for surface-supplied diver communications represents the greatest potential for intelligible communications. The amplifier case is the heart of the system and contains the amplifier, the tender's reproducer, the control switches, the volume control, the power switch and the diver's jacks. These components are contained in a weatherproof wood, plastic, or metal case for protection. Most units are powered by internal, 6- or 12-volt, lantern-type batteries, which provide continuous operation on moderate volume output for 25 hr or more. Some units feature connections for external power supply. Other units incorporate redundant batteries so that there is always a spare in case of emergency.

The tender's reproducer, mounted in the amplifier case, serves as a loud speaker when the diver is talking and as a microphone when the tender is talking. In most units the tender must depress a spring-return "tender-to-diver" switch to communicate. When the switch is in a normal position, the tender hears all divers connected to the unit. Amplifiers are available in one-, two-, or three-diver models.

On multiple-diver units, separate spring-return control switches marked "diver to diver" are used for diver-to-diver communications. By pressing a switch, a designated diver may communicate with another diver. The control-switch configuration will depend on the make of the unit. Effective use of this feature requires a certain amount of circuit discipline. All switching is done by the tender. If Diver No. 1 wishes to speak with Diver No. 2, he calls, "Diver 1 to Diver 2." The tender presses the tender-to-diver key and says, "Go ahead Diver 1" or "Roger Diver 1," and immediately releases the tender to diver key and holds Diver No. 1-to-Diver No. 2 key. At the end of the message, Diver No. 1 will say "over" if he requires a reply from Diver No. 2 or "out" if transmission is completed. The tender maintains the

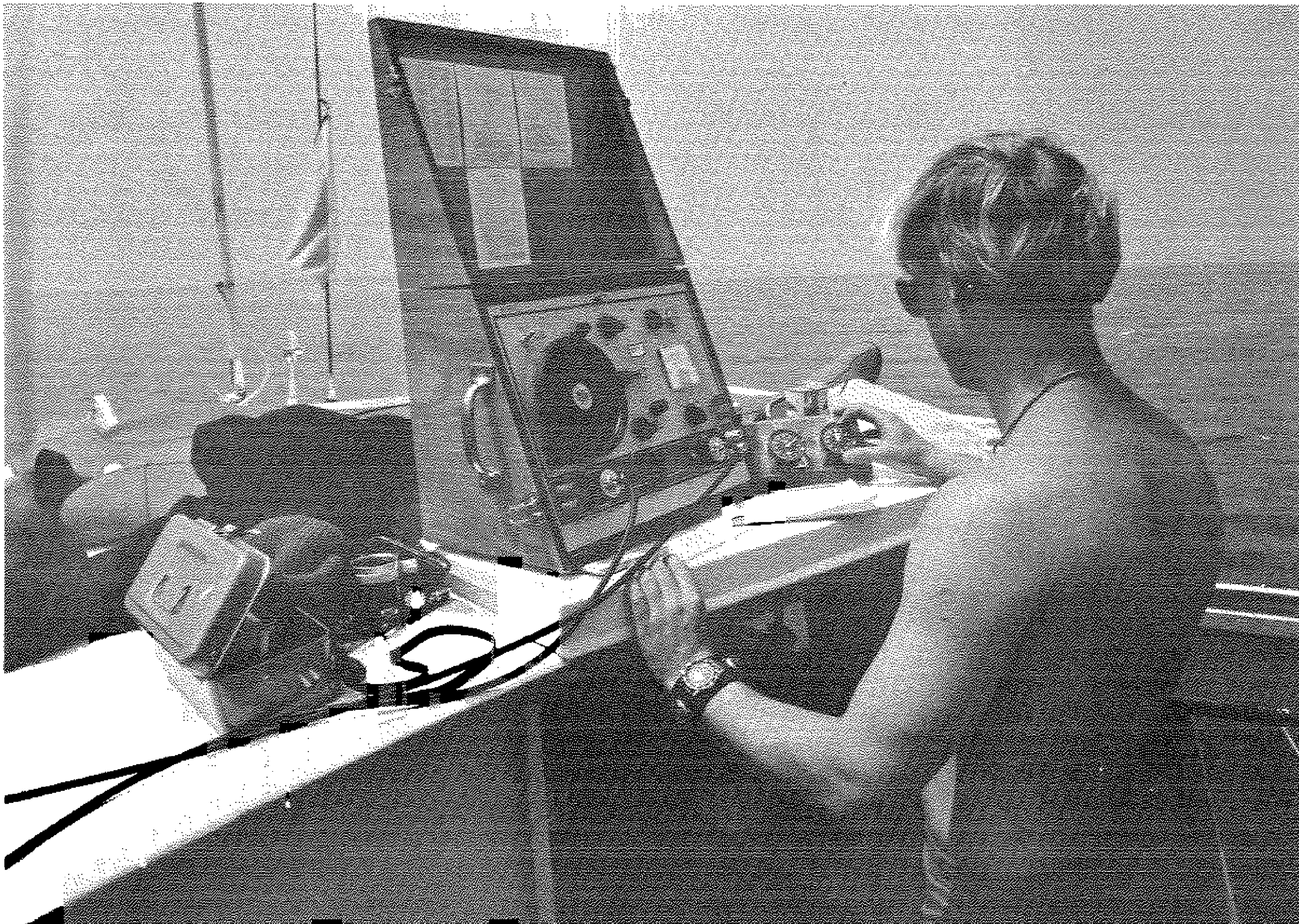

Figure 7-8. Hardwire Communications System and Stop Watches for Timing Dives (Photo by Somers)

circuit discipline by controlling transmissions. He acknowledges completion of diver-to-diver transmission.

A microphone is located in the diver's helmet or oral-nasal mask assembly and earphones are placed next to the diver's ears to eliminate noise to the diver and acoustic feedback to the microphone. The diver has no switches or keys to activate. Volume and tone are controlled by the tender. The diver may call for adjustment in volume or tone during the dive.

Details of the communications wire are discussed in Section 7.5.2. The type of surface plug (or jack) will depend on the make of the unit.

All communications should be concise with clean and distinct pronunciations of words: avoid lengthy sentences. Keep communication requirements limited to only those necessary for safety and completion of the mission. Communications procedures are essentially the same as those used for radio communication. The tender should be constantly alert for calls from the diver. The following terms are frequently used:

Over	=	tender or diver completes transmission and requires a reply.
Say Again or Repeat	=	transmission not understood and must be repeated.
Roger	=	transmission understood.

On critical transmissions the tender may require the diver to repeat the transmission he just received to ensure accuracy. This is common procedure for ascent orders and decompression schedules. The diver may also request a repeat if he is transmitting critical data. Repeat transmission requirements may be prearranged or on a given request by the diver or tender by saying, "repeat" or "repeat my last."

The diver communication system is designed to be as rugged as possible; however, it fundamentally remains a piece of electronic equipment and must be protected from shock and moisture. Most mask and helmet components are only water resistant and *not waterproof*. They must be especially protected from salt water. The unit should be maintained and repaired in accordance with manufacturer's instructions.

7.7 Accessory Equipment

See Figure 7-9.

7.7.1 Coveralls

Coveralls of cotton, nylon, or light canvas are used to protect the diving suit against wear and chafe. Standard workman's coveralls are adequate; however, nylon "flight-suits" are more satisfactory. The coveralls should not be so tight that they inhibit the diver's movements nor should they be extremely loose.

7.7.2 Weight Belt

The weight belt (Figure 7-9c) provides the necessary ballast to overcome the positive buoyancy of the breathing equipment and dress. Generally, lead weights (5 lb each) are secured to a leather or fiber belt with bolts. The belt is approximately 4 in. wide and fitted with a quick-release fastener. Some belts are also equipped with shoulder and/or jockstraps. The use of SCUBA diving weight belts with heavy surface-supplied equipment is not recommended. Leather belts should be periodically coated with neat's-foot oil.

7.7.3 Shoes and Leg Weights

Weighted shoes (Figure 7-9d) or leg weights are used in conjunction with the weight belt to overcome positive buoyancy and to give stability to the diver. Standard weighted shoes consist of a lead or brass sole; hardwood upper sole and either canvas or leather uppers; lacing cord; leather straps to hold the shoe in place; and a protective brass toe piece. US Navy lightweight shoes weigh approximately 20 lb/pair.

Leg weights consist of one large or several small weights attached to leather or nylon straps. The straps are fitted with buckles for securing the weights to the diver's legs near the ankle. Weight varys from 4 to 10 lb each, depending on the preference of the diver. Leg weights provide considerably improved stability and safety (against blowup) since divers in variable-volume suit can swim with relative ease while wearing fins and leg weights.

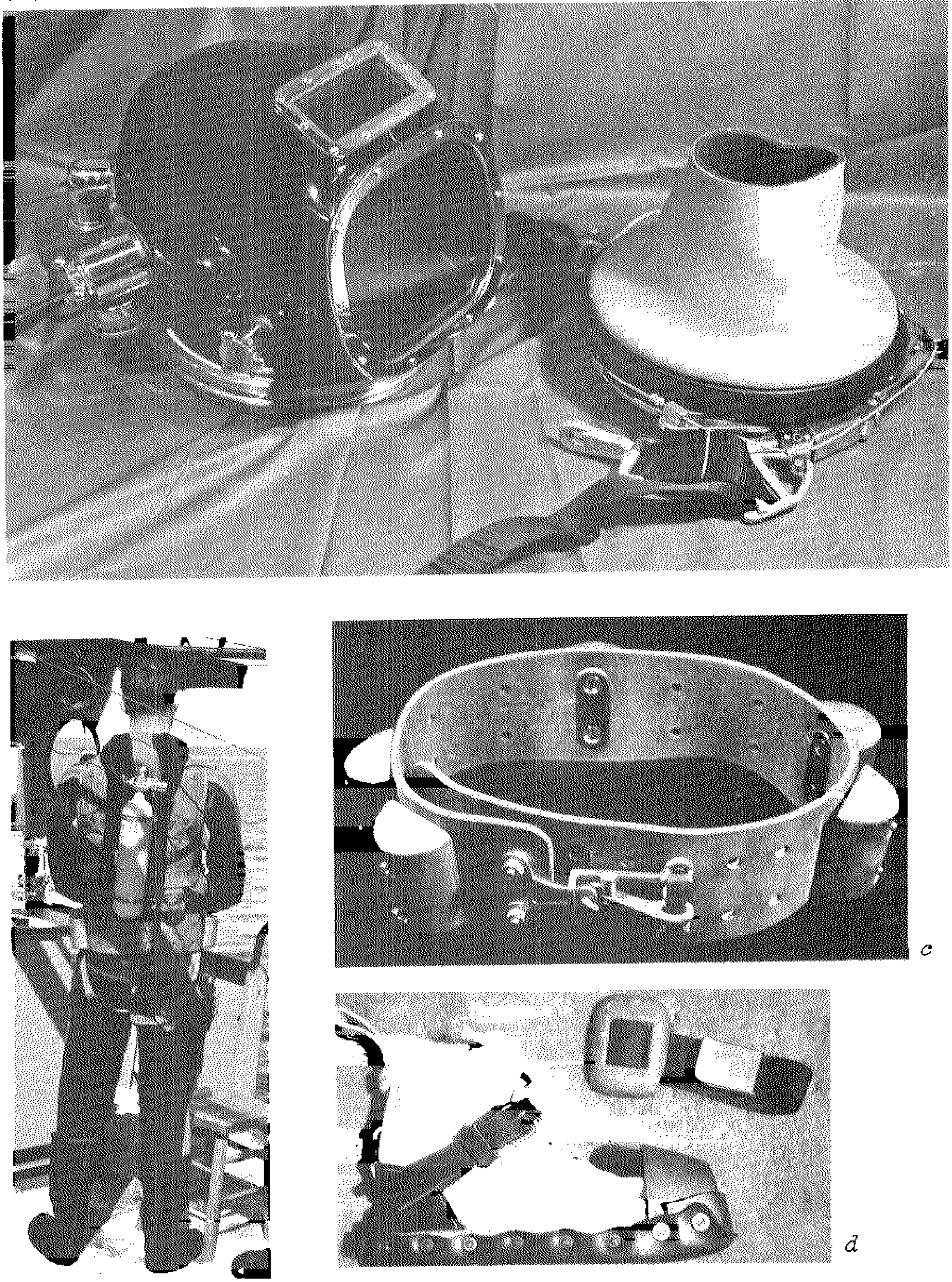

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Figure 7-9. Surface-Supplied Diving Components: (a) Aquadyne Lightweight Helmet and Neckring for Use with Wet Suit, Variable-Volume Suit or Without a Suit; (b) Diver Wearing Hot-Water Suit, Emergency Gas Bottle and Modified Parachute Body Harness; (c) Weight Belt with Quick-Release Buckle; (d) Diver's Lightweight Shoe and Leg Weight (Photos by Somers)

7.7.4 Harness

The diver should wear some sort of harness assembly to facilitate attachment of the umbilical assembly. The harness should be designed to withstand a minimum of 1000 lb pull in any direction and must prevent strain from being placed on the diver's mask or helmet when a pull is taken on the hose assembly. A modified parachute harness (Figure 7-6b) has proven satisfactory for this purpose as well as the lighter weight, "Gulf" harness (Figure 7-6d).

7.7.5 Emergency Gas Supply System

A self-contained emergency gas supply system (or bailout unit) is used in conjunction with surface-supplied diving equipment for work in excess of a 60 ft depth or when working in tunnels, pipes, etc., or where there is specific danger of entanglement. The unit (Figures 7-6a, d; 7-9b) consist of a SCUBA cylinder assembly, a reduction regulator (first stage of a standard single-hose regulator), and a backpack-harness assembly. The capacity of the SCUBA cylinder assembly will vary from 10 ft^3 to 140 ft^3, depending on the diver and the situation. The self-contained emergency gas may be fed directly into the mask through a special attachment on the side valve or directly into the diver's air hose assembly. In the latter case, a check valve should be located between the intersection of the emergency gas supply hose and the primary surface supply hose. A valve is useful for metering the gas into the helmet and facilitating rapid activation of the emergency unit. Aquadyne, Incorporated manufactures a special manifold assembly complete with check valve and on-off valve (Figure 7-6a, c).

7.7.6 Head Protectors

Head protectors (Figure 7-6a, d) are used with the free-flow/demand mask to prevent injury to the diver's head. The helmet-style protector is generally constructed of fiber glass and designed to absorb shock either through internal padding or special attachment to the mask. Head protectors are recommended when working under boats or other types of obstructions.

7.7.7 Knife

All divers should carry a sharp diver's knife in a proper scabbard.

The scabbard should be secured to the diver's belt, leg, or arm. The diver's knife is discussed in more detail in Section 6.7.5.

7.8 Diving Procedures

In addition to the diving procedures previously discussed, the following must be considered for surface-supplied diving operations.

7.8.1 Preliminary Preparations

In addition to general dive planning given in the chapter on diving procedures, the following procedures should be carried out prior to the dive:

1. Assemble air supply system, including compressor and/or high-pressure cylinders and umbilical assembly, and pressure test for leaks.

2. When using high-pressure cylinders, gauge and mark each cylinder to ensure that all personnel know which cylinders are full and are to be used for the dive.

3. Check air regulation or control system including emergency switching to secondary air supply and back-up regulator (if so equipped).

4. Mask or helmet should be prepared as previously discussed.

5. Prepare chamber so it is ready for immediate use in the event of an emergency and have personnel standing by to operate chamber.

6. Assemble all equipment for final check by *tender*, *diver*, and *dive supervisor*.

7. The tender and/or dive supervisor will enter necessary information into the "rough" diving log.

7.8.2 Calculating Air Requirements

The most important consideration in surface-supplied diving is that of providing the diver with an adequate breathing gas supply. Since 3 percent carbon dioxide concentration at atmospheric pressure is about the maximum that can be tolerated without distress, it is essential that the equivalent partial pressure not be exceeded in the helmet or mask. For free-flow mask and lightweight helmet ventilation, a minimum air supply of 1.5 ft^3./min (measured at the absolute pressure of the diver's depth) is adequate only for light work. Ideally, the volume of air available to the diver should be at least 4.5 ft^3/min at depth. To determine the volume of free air (as measured at the surface) required by a diver, the following formula may be used (US Navy, 1970):

$$S = 4.5N\left(\frac{D + 33}{33}\right),$$

where S is air supply in cubic feet of free air per minute, N is the number of divers using a single air source, and D is the depth in feet.

A similar formula used by University of Michigan divers to calculate flow rate is

$$R_f = 4.5P_a,$$

where R_f is flow rate in cubic feet per minute and P_a is ambient pressure at working depth in atmospheres. This result must, of course, be multiplied by the number of divers using a given air source.

For example, one diver working at a depth of 100 ft using a lightweight helmet would require

$$R_f = 4.5(4)$$

$$= 18 \text{ ft}^3/\text{min}.$$

Naturally, the diver will regulate the volume in accordance with his work level and personal requirements. However, the air source should be capable of providing the 4.5 ft^3/min surface equivalent.

The free-flow/demand mask (and surface-supplied demand regulator or hookah) must also have a 4.5 ft^3/min surface equivalent flow rate when used in the free-flow mode. However, demand-mode requirements are similar to those of SCUBA and will vary from .75 to 3 ft^3/min surface equivalent, depending upon the diver's activity level.

Flow rate for demand mode may be calculated using the following formula:

$$R_d = C_s(P_a),$$

where R_d is demand flow rate (ft^3/min), C_s is surface consumption rate (ft^3/min), and P_a is ambient pressure at working depth in atmospheres.

When using a free-flow mask or lightweight helmet, a hose pressure of at least 50 lb/in^2 over ambient is required for divers in less than 120 ft depth and 100 lb/in^2 over ambient is required for depths exceeding 120 ft. Hose pressure may be calculated using the following formulas:

$$P_h(<120) = .445D + 65$$

$$P_h(>120) = .445D + 115\ ,$$

where $P_h(<120)$, $P_h(>120)$ equal minimum hose pressure for less than 120 ft and greater than 120 ft, respectively, and D is working depth. For example, the hose pressure for a helmet diver working at 100 ft is

$$P_h(<120) = .445(100) + 65$$
$$= 110 \text{ lb/in}^2\ .$$

In some cases, small compressors will not be capable of delivering pressures recommended here. Always maintain a pressure of *at least 1 atm in excess of absolute bottom pressure.* This is necessary to provide the diver with immediate available pressure in the event of a fall, thereby possibly preventing barotrauma, or increase flow requirements. Hose pressure requirements are also increased when using exceptionally long tethers. Graphs given by Hansen (1972) may also be used to determine flow rate and hose pressure (Figure 7-3).

Recommended hose pressure (3/8-in. ID hose) for a free-flow/demand mask (ana hookah) is 100 lb/in^2 in excess of ambient pressure at working depth,

$$P_{h(f/d)} = .445D + 115 ,$$

where $P_{h(f/d)}$ equals minimum hose pressure for free-flow/demand mask. Modern free-flow/demand masks are designed to function at hose pressures of 50-200 lb/in^2 (depending on make) over ambient. The 100 lb/in^2 figure is considered most satisfactory.

7.8.3 Dressing Procedures

The dressing procedures will depend upon the type of diving dress or suit and helmet or mask used. Specific instructions for donning various types of diving suits are included in this manual under cold-water diving or in special manuals supplied by the suit manufacturer. Instructions for preparation of masks and helmets have been discussed previously. Prior to starting dressing procedures, the air supply system should be operational and the mask or helmet completely prepared for diving. The following is a generalized dressing procedure applicable to most surface-supplied diving systems:

1. Don diving dress or suit with assistance from the tender(s) if necessary.

2. Don diver's harness, secure, and adjust.

3. If weighted diving shoes or ankle weights are used, they are placed on the diver by the tender and secured. If fins are used, they may be donned later with the assistance of the tender.

4. Don neckring and secure if helmet is to be used.

5. Don and adjust weight belt.

6. Secure knife to belt, leg, or arm (diver's preference).

7. With the diver or a second tender holding the mask or helmet, secure bailout unit.

8. Don mask or helmet and secure mask harness or helmet clamp. A separate head protector used with the Aquadyne mask is now donned.

9. Secure the umbilical assembly to harness.

10. The tender ensures that the diver is properly dressed, that all equipment is functioning properly, and informs the diving supervisor that the diver is ready.

7.8.4 The Dive

When all personnel have completed dressing-in, checking equipment, and final briefings, the captain (if diving from a vessel) is notified that the diver(s) is (are) ready to enter the water. He must give clearance before the diving operation can commence. Entry technique will depend upon staging area or type of vessel. The diver should enter the water using a ladder or be lowered on a diving stage. Jump entries are discouraged. Upon entering the water, the diver should stop at the surface to make a final equipment check. The dive procedure is as follows:

1. Adjust buoyancy if necessary. Whether the diver is weighted neutral or negative will depend on the mission requirements.

2. Ensure that air supply system, helmet or mask, and communications are functioning properly. If not, corrections must be made prior to descent. *Never* dive with malfunctioning equipment.

3. The tender should also verify that all equipment is functioning satisfactorily.

4. The diver is given permission to descend by the diving supervisor.

5. The diver descends down a descent or "shot" line. A timer is started when the diver begins his descent. Descent rate will depend on the diver; however, it should generally not exceed 75 ft/min.

6. The diver must equalize pressure in his ears and sinuses during descent. If equalization is not possible, the dive must be terminated.

7. When descending in a tideway or current, the diver should keep his back to the current so he will be forced against the descent line.

8. When the diver reaches the bottom, he should inform the tender of his status.

9. Regulate buoyancy and regulate air flow if necessary before releasing descent line.

10. Attach distance line, if used, and proceed to work area. A distance line should be used when visibility is extremely poor and the diver cannot see his descent line from a distance.

11. Upon leaving the descent line, proceed slowly to conserve energy. It is advisable to carry one turn of the umbilical hose in your hand.

12. Pass over, not under, wreckage and obstructions.

13. If moving against a current, it may be necessary to assume a crawling position.

14. If the diver is required to enter wreckage, tunnels, etc., a second diver should be down to tend his umbilical hose at the entrance.

15. Avoid excessive exertion. The tender should monitor breathing rate and call for the diver to *"stop, rest, and ventilate"* as required. Also, avoid excessive excitement. This can enhance the onset of fatigue. Slow methodical efforts are always best in an emergency.

16. The tender must keep the diver *constantly* informed of his bottom time. Always notify the diver a few minutes in advance of termination time so he can complete his task and prepare for ascent.

7.8.5 Tending the Diver

Surface tenders should also be experienced divers. The most effective assistance can be given only by a tender who is familiar with the equipment, procedures, safety precautions, conditions, and difficulties that are inherent in diving. It is the tender's responsibility to see that the diver receives proper care while both topside and underwater. He must check all equipment before sending the diver down.

While the diver is submerged, the tender handles the umbilical assembly, maintains communications, and monitors air flow. The usual means of communications between diver and tender is by intercom; however, it is important that basic line signals be memorized and practiced so they will be recognized instantly in the event of intercom failure or if apparatus not fitted with an intercom is used. The following are line or hand signals as given by the US Navy (1970) for air diving:

•*Tender to Diver*•

1 pull---------------Are you all right? (When the diver is descending, 1 pull means stop.)

2 pulls--------------Going down. (During ascent, you have come up too far. Go back down until I stop you.)

3 pulls--------------Stand-by to come up.

4 pulls--------------Come up.

2-1 pulls------------I understand, or answer the telephone.

•*Diver to Tender*•

1 pull---------------I am all right.

2 pulls--------------Give me slack or lower me.

3 pulls--------------Take in my slack.

4 pulls--------------Haul me up.

2-1 pulls------------I understand, or answer the telephone.

3-2 pulls------------Give me more air.

4-3 pulls------------Give me less air.

•*Emergency Signals: Diver to Tender*•

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.

Special signals may be prepared to meet mission requirements.

In tending the diver's umbilical assembly, or lines, the tender must not hold the diver's line so taut as to interfere with the diver's work. The diver should be given 2-3 ft of slack when he is on the bottom, but not so much that he cannot be felt from time to time. Signals cannot be received on a slack line; consequently, the diver's lines must be kept in hand with proper tension at all times.

Line-pull signals consist of a series of sharp, distinct pulls, strong enough for the diver or tender to feel but not so strong as to pull the diver away from his work. When sending signals, take all of the slack out of the line first. Repeat signal until answered. The only signal not answered when received is the emergency "haul me up," and "come up" is delayed until the diver is ready. Continued failure to respond to signal may indicate that there is too much slack in the line, the line is fouled, or the diver is incapacitated. If contact with the diver is lost, the following procedures should be followed:

1. If intercom communications is lost, the tender should attempt line-pull communications immediately.

2. Depending upon diving conditions and previous arrangements made during planning, the dive may be terminated or continued to completion with line-pull signals. Generally, in research diving, it is best to terminate the dive to resolve the problem or reorganize the dive plan.

3. If the tender receives no immediate line-pull signal reply from the diver, he should take a greater strain on the line and signal again. Considerable resistance to the tender's pull may indicate that the umbilical line is fouled. A stand-by diver should be dispatched as soon as possible.

4. If tender feels sufficient tension on the line to conclude that it is still attached to the diver, yet receives no signals, he must assume that the diver is unconscious. In this event, he should dispatch a stand-by diver immediately.

5. If a stand-by diver is unavailable, or it is considered unwise to use one, the diver must be pulled very slowly to the surface. Prepare to administer first aid and recompression. Note: If the diver is wearing

a closed-dress or variable-volume dry suit, this procedure is used only as a last resort. Subsequent blowup is almost unavoidable without the assistance of another diver.

The tender should continuously monitor the diver's depth and underwater time. He should inform the diver several minutes before the expiration of bottom time so that the diver can make necessary preparations for ascent. In addition, he must continually monitor the diver's activity. For example, the tender can frequently evaluate the diver's exertion by counting the number of breaths per minute. Experienced tenders will learn the diver's normal breathing rate. Significant increase in breathing rate may indicate potential over-exertion situations. The tender may ask the diver to stop work, rest, and ventilate his helmet or mask.

The tender may also have to serve as timekeeper. This job includes keeping an accurate record of the dive time and details of the dive. When possible, a separate timekeeper should be used or the timekeeper duties handled by the diving supervisor.

7.8.6 FOULING

A surface-supplied diver's umbilical line may become fouled in mooring lines, wreckage, or underwater structures, or the diver may be trapped by the cave-in of a tunnel or shifting of heavy objects. The surface-supplied diver is in a much better situation to survive since he has a virtually unlimited air supply and generally the ability to communicate, thus facilitating rescue operations. Consequences of fouling may result in fatigue, exposure, and prolonged submergence, with subsequent prolonged decompression. If the diver becomes fouled, he should (1) remain calm, (2) think, (3) describe the situation to his tender, and (4) systematically attempt to determine the cause and to clear himself. He should use a knife cautiously to avoid cutting portions of the umbilical assembly. If efforts to clear himself prove futile, he should call for a stand-by diver and calmly wait. Struggling and panic can only make the situation worse.

Divers should proceed cautiously underwater and attempt to recognize obstructions, etc. which might cause fouling. Pass over or around if possible, not under. Proper precautions can usually avert fouling.

7.8.7 Blowup

Blowup is a hazard for the diver using a closed-dress (deep-sea or lightweight helmet connected to dry-type suit outfit) or variable-volume dry suit (UNISUIT or equivalent). Blowup is caused by overinflation of the dress or suit, too strong or rapid of pull by the tender, or by the drag of the current causing the diver to lose hold of the bottom or descending line and thus sweeping him to the surface. Accidental inversion of the diver, with subsequent filling of the legs with large amounts of air, may result in an uncontrolled blowup. This hazard even exists for the SCUBA diver when using a variable-volume suit.

Accidental blowup may result in injuries such as

- air embolism,
- decompression sickness, and
- physical injury from head striking on some object such as the bottom of the ship.

The diver must be certain that all exhaust valves are functioning properly before descending. The diving suit or dress should be of proper size (especially length) to avoid excessive space in the legs for accumulation of air should the diver become inverted. This is especially true for divers wearing variable-volume suits. Divers must be trained under controlled conditions, preferably in a swimming pool, in the use of all closed-type diving suits, regardless of previous experience with other types. "Controlled" blowups employed by some divers for ascent should be discouraged.

A blowup victim should not be allowed to continue the dive. If the diver appears to have no ill effects and is still within the no-decompression range as prescribed by the tables, he should return to 10 ft and decompress for the amount of time that would normally be required for ascent from his working depth. He should then be surfaced, dressed out, and observed for signs of air embolism and decompression sickness.

If the victim is near or within the decompression requirements, he should be recompressed in a chamber and decompressed in accordance with surface decompression procedures if it appears that surface decompression tables offer an immediate solution. If not, the victim should be recompressed in a chamber to 100 ft for 30 min and treated in accordance with Table 1-30 (US Navy treatment tables; see Appendix C). If no chamber is available and the victim is conscious, he should be treated in accordance with procedures for interrupted or omitted decompression. If the victim is unconscious, the procedures for handling victims of air embolism and decompression sickness should be followed.

7.8.8 Ascent

When bottom time is up or the mission is completed, the diver will return to his ascent line and signal his tender that he is ready for ascent. The ascent procedure is as follows:

1. The tender will pull in excess umbilical line and take a slight strain on the umbilical line. He will pull slowly and steadily at the prescribed rate (generally 60 ft/min).

2. A timer is started at the beginning of ascent and the tender will watch the timer and pneumofathometer to control ascent rate.

3. The diver will regulate his buoyancy, if using a closed- or variable-volume suit, to aid the tender. Be cautious to avoid overinflation of dress and subsequent "blowup."

4. The diver should never let go of his line, and may "climb" the line to aid the tender.

5. The tender or dive supervisor must inform the diver well in advance of his decompression requirements. A diving stage may be required for long decompressions.

6. When decompression is completed, the diver is taken on board via the ladder or diving stage.

7.8.9 Postdive Procedures

The divers should be helped from the water and aided with removal of equipment by surface personnel. The divers should be observed for signs of sickness or injury resulting from the dive and warming procedures should be commenced as soon as possible. Preventive maintenance on equipment should be undertaken as soon as possible after the dive. The divers and tenders should report any defects noted during or after the dive and the defective equipment should be tagged for corrective maintenance. Divers should be debriefed and the log completed.

7.9 REFERENCES

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8 DIVING ENVIRONMENT

8.0 Diving Environment

To dive safely, the diver must have a working knowledge of waves, tides, currents, marine life, and water quality. Relatively few of the thousands of marine organisms constitute a real hazard to the diver. However, ignorance and carelessness on the part of the diver can lead to severe injury from a few marine organisms. Lack of understanding and respect for ocean currents and surf is probably of more serious consequence to the diver.

Unfortunately, inland divers are unable to receive proper training in ocean diving techniques during their basic courses. Safe diving in ocean currents, proper surf entries, and diving in kelp growths require special instruction. Consequently, the inland diver, whether novice or experienced, must acquire special instruction when he makes his first trip to the ocean. Furthermore, a diver who learns the proper techniques for work in the currents of the Florida Keys must still acquire additional ocean training when he travels to the surf beaches of the Pacific, the oil rigs of the Gulf, or the wrecks off the New England coast.

This chapter on the diving environment is designed to provide the diver with a general understanding of the physical characteristics and some of the living organisms common to lakes and oceans. The descriptions of diving techniques are included to give the diver a better understanding of how to safely handle himself under various conditions.

These written descriptions, however, are *not sufficient in themselves* to prepare the inland diver for an ocean experience. He must acquire special instruction and dive under the supervision of an instructor or experienced ocean diver whenever he desires to advance his qualifications to include ocean diving. Proper training, common sense, good judgment, and *physical fitness* are prerequisites for ocean diving.

8.1 Waves, Tides, and Related Currents

8.1.1 Waves at Sea

Waves are a series of undulations generally propagated on the water's surface by the force of the wind. Ocean waves are usually measured in terms of their length, height, and period. *Wave length* is the horizontal distance between successive crests, *height* is the vertical distance between crest and trough, and *period* is the time required for the movement of two successive crests (or troughs) past a given reference point (Figure 8-1).

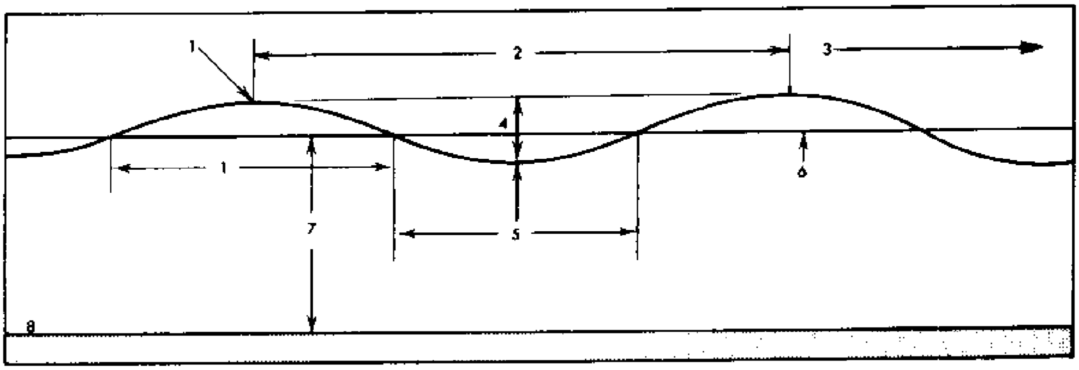


Figure 8-1. Wave Characteristics: (1) Wave Crest; (2) Wave Length; (3) Direction of Wave Travel; (4) Height; (5) Wave Trough; (6) Still-Water Level; (7) Depth; (8) Ocean Bottom (Baker et al., 1966)

Waves are moving *forms*, a translation of energy from water particle to water particle, with very little mass transport of the water. The volume of water transported by the passing wave form is negligible for waves of small steepness (under normal conditions) and can be disregarded for all practical purposes. The water particles within a wave move in an orbital motion (Figure 8-2). The surface particles move in a circular orbit exactly equal to wave height; below the surface, the orbits become smaller and, in an ideal deep-water wave, the diameters diminish with increasing depth.

Common water waves develop under the influence of newly formed winds (Figure 8-3). The air pressure changes on the surface and the frictional drag of the moving air of these winds develop ripples on the water surface which evolve into waves whose dimensions tend to increase with the wind velocity, duration, and *fetch* (the length of the area over which the wind is blowing). Energy is transferred directly from the atmosphere to the water. The waves grow in height and steepness (height/length ratio) until, in some cases, the wave breaks at a steepness of about 1:7 to form whitecaps. In a steady

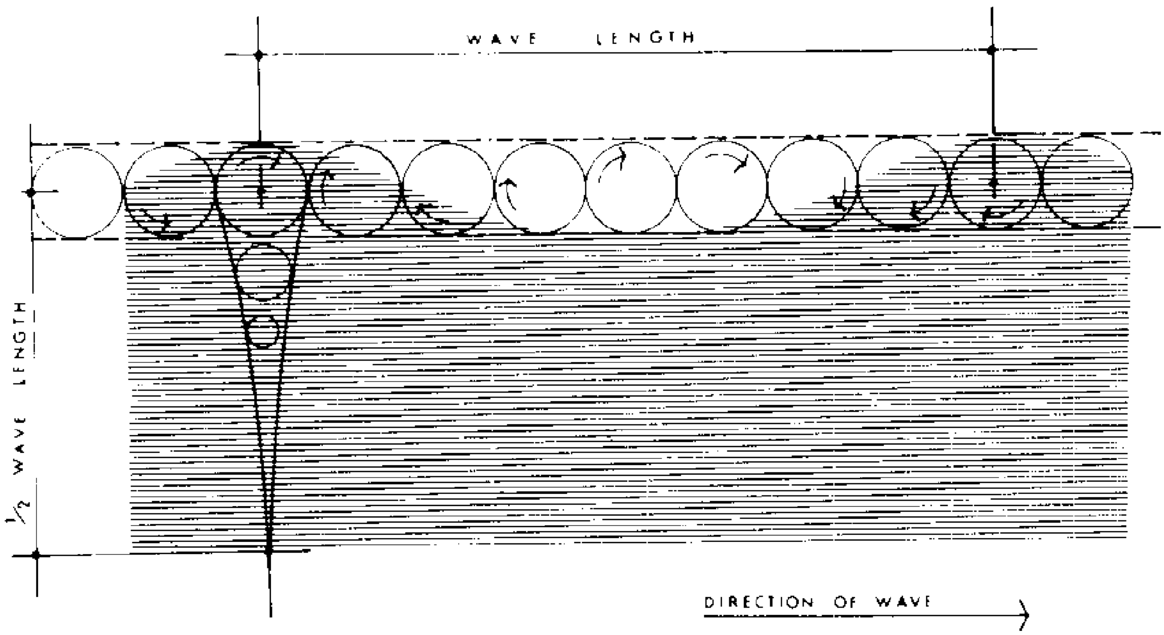


Figure 8-2. Cross-Section of Wave (Traveling from Left to Right): Circles Represent Water Particles in the Wave

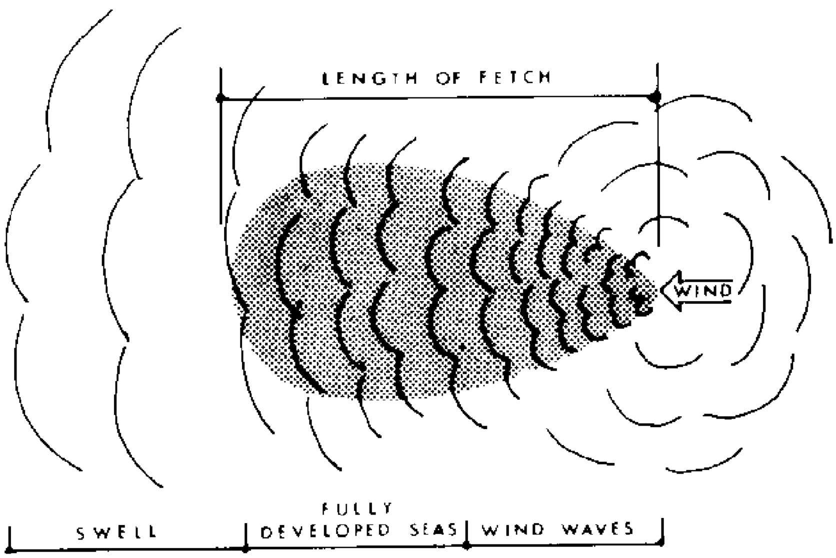


Figure 8-3. Diagram of Wave Development

wind, waves of various dimensions develop with progressively increasing heights and periods until a steady state is reached in which the sea is fully developed for the prevailing wind speed. This steady state is maintained as long as the wind remains constant. These waves, generated locally by a continuing wind, are known as *sea*. Although this local sea originated in a single wind system, it is a combination of many different superimposed wave trains with various heights and directions. This gives the appearance of a rapidly changing ocean surface.

Sea persists only in the fetch area and for the duration of the generating wind. When the wind velocity decreases or the wave leaves the fetch area, it is called a *swell wave*. Swell waves are characterized by long, rounded crests and decreased wave heights relative to sea waves, and they are more regular in height, period, and direction. As a swell wave progresses, in absence of a sustaining wind, its height decreases, with a consequent reduction in wave steepness. This change in wave form is known as *wave decay*. One cause of wave decay is a loss of energy from the wave that is brought about by internal friction, wind resistance, current action, and the effects of solid objects (ice, seaweed, land masses, etc.) in the path of the wave.

8.1.2 Waves in Shallow Water

As the wave forms approach shore and move across shallow bottoms, they are reflected, diffracted, and refracted. When a wave encounters a vertical wall, such as a steep rocky cliff rising from deep water or a seawall, it is *reflected* back upon itself with little loss of energy (Figure 8-4). If the period of the approaching wave train is regular, a pattern of standing waves may be established in which the orbits of the approaching and reflected waves modify each other in such a way that there is only vertical water motion against the cliff and only horizontal motion at a distance out of one-fourth wave length. Submerged barriers, e.g., as a coral reef, will also cause reflections.

When a wave encounters an obstruction, the wave motion is *diffracted* around it (Figure 8-5). As the waves pass the obstruction, some of their energy is propagated sideways due to friction with the obstruction, and the wave crest bends into the apparently sheltered area.

As the wave train moves into shallow water, the friction on the bottom causes it to slow. Since different segments of the wave front are moving in different depths of water, the crest bend and the wave

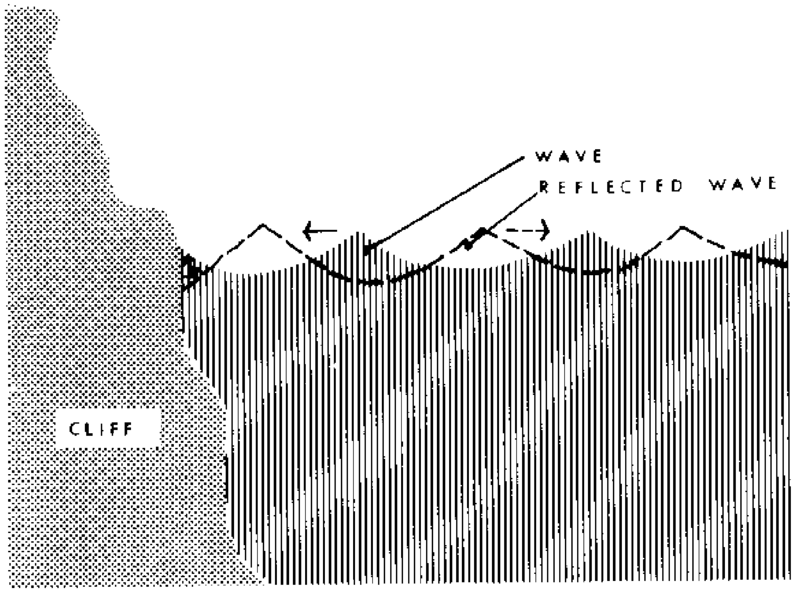


Figure 8-4. Wave Reflection

direction constantly change. This is called *refraction* (Figure 8-6). Essentially the wave crest or front parallels the contours of the bottom. A simple example of refraction is that of a set of waves approaching a straight shoreline at an angle. The part of each wave nearest shore is moving in shallower water and, consequently, is moving slower than the part in deeper water. Thus the wave fronts tend to become parallel to the shoreline and the observer on the beach will see larger waves coming directly toward him. On an uneven shoreline the effect of refraction is to concentrate the wave energy on points of land and disperse the wave energy in coves or embayments. Submarine depressions, i.e., canyons, also cause the waves to react in a similar fashion. The waves

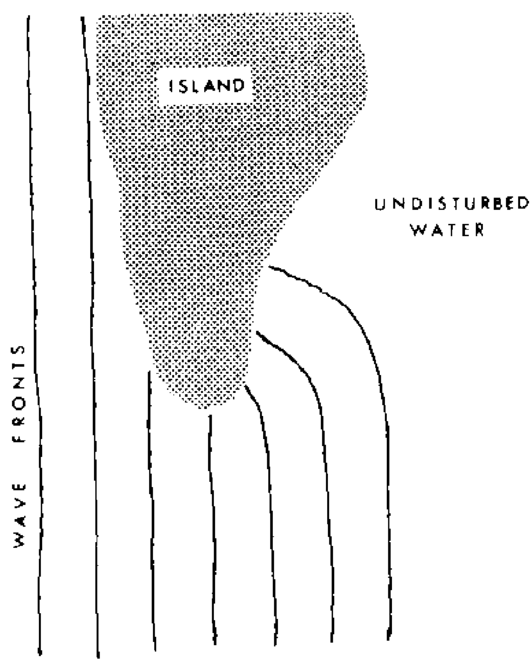


Figure 8-5. Wave Diffraction

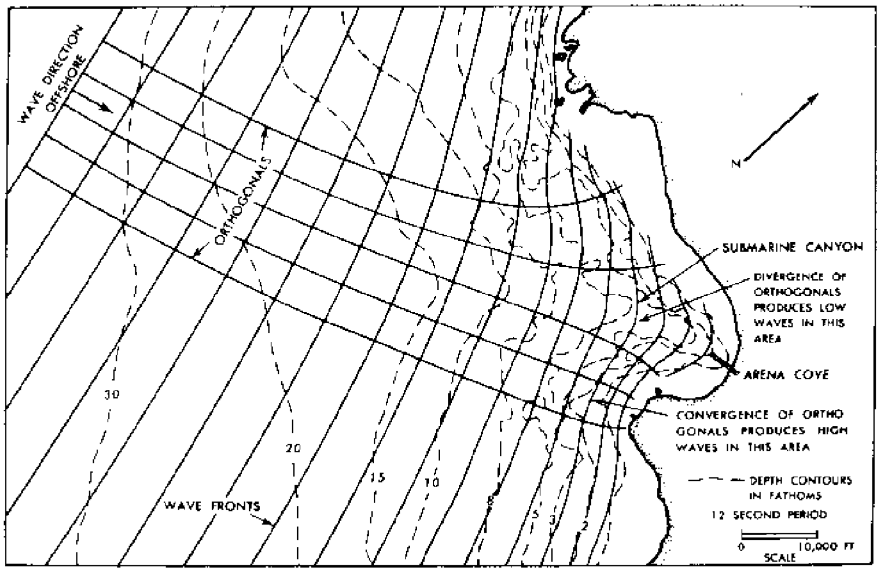


Figure 8-6. Wave Refraction (Baker et al., 1966)

dissipate over the canyon and increase in intensity on the perimeter of the canyon. Any irregularities in bottom topography in *shallow* waters will cause refraction to some degree.

A knowledge of the behavior of waves as they enter shallow water is of considerable significance to SCUBA divers when planning entries from shore. By observing wave patterns and by studying the shoreline configuration and bottom topography, the diver can select the locations where wave energy and, consequently, height is least. This will aid entry and nearshore work.

8.1.3 Surf

As swell, the waves traverse vast expanses of ocean with little modification or loss of energy. However, as the waves enter shallow water, the motion of the water particles beneath the surface is altered. When the wave enters water of depth equal to or less than one-half the wavelength, it is said to "feel bottom." The circular orbital motion of the water particles becomes elliptical, flattening with depth. Along the bottom, the particles oscillate in a straight line parallel to the direction of wave travel.

As the wave "feels bottom," its wave length decreases and steepness increases. Furthermore, as the wave crest moves into water where the depth is about twice that of the wave height, the crest changes from rounded to a higher, more pointed mass of water. The orbital velocity of the water particles at the crest increases with increasing wave height. This sequence of changes is the prelude to the breaking of the wave. Finally, at a depth of approximately 1.3 times the wave height, when the steepest surface of the wave inclines more than 60 degrees from the horizontal, the wave becomes unstable and the top portion plunges forward. The wave has broken; this is *surf* (Figure 8-7). This zone of "white water," where the waves finally give up their energy and where systematic water motion gives way to violent turbulence, is the *surf zone*. The "white water" is a mass of water with bubbles of entrapped air.

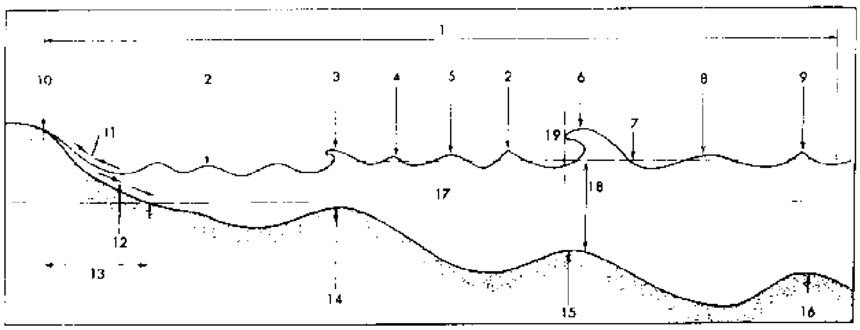


Figure 8-7. (1) Surf Zone; (2) Translatory Waves; (3) Inner Line of Breakers; (4) Peaked-up Wave; (5) Reformed Oscillatory Wave; (6) Outer Line of Breakers; (7) Still-Water Level; (8) Waves Flatten Again; (9) Waves Break Up but Do Not Break on This Bar at High Tide; (10) Limit of Uprush; (11) Uprush; (12) Backrush; (13) Beach Face; (14) Inner Bar; (15) Outer Bar (Inner Bar at Low Tide); (16) Deep Bar (Outer Bar at Low Tide); (17) Mean Lower Low Water (MLLW); (18) Breaker Depth, 1.3 Height; (19) Plunge Point (Baker et al., 1966)

Having broken into a mass of turbulent foam, the wave continues landward under its own momentum. Finally, at the beach face, this momentum carries it into an uprush or swash. At the uppermost limit, the wave's energy has diminished. The water transported landward in the uprush must now return seaward as a backrush, or current flowing back to the sea. This seaward movement of water is generally not evident beyond the surface zone or a depth of 2-3 ft. This backrush is *not* to be considered as an *undertow*. Undertow is one of the most ubiquitous myths of the seashore. These mysterious mythical currents are said to flow seaward from the beach along the bottom and "pull swimmers under." There are currents in the surf zone and other water movements which may cause trouble for swimmers, but not as just described. Such problems will be discussed later.

Once the wave has broken, if the water deepens again, as it does where bars or reefs lie adjacent to shore, it may reorganize into a new wave with systematic orbital motion. The new wave is smaller than the original one and it will proceed into water equal to 1.3 times its height and also break. A diver may use the presence of waves breaking offshore as an indicator for the location of rocks, bars, etc. and plan his entry or approach to shore accordingly (Figure 8-8).

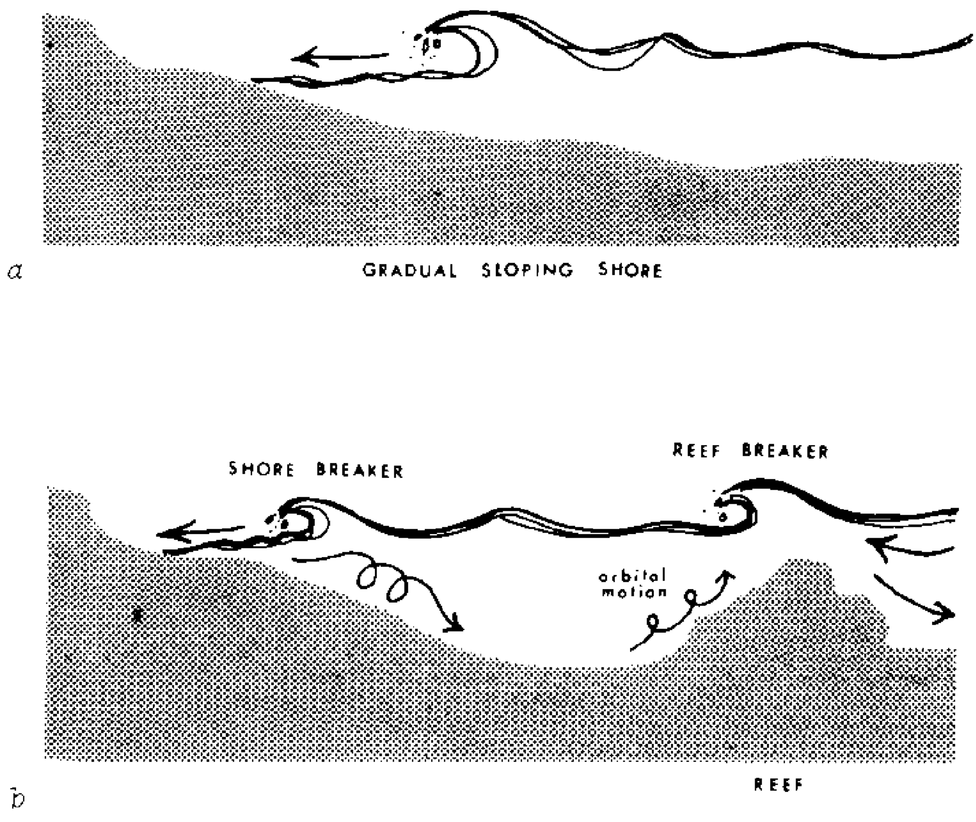


Figure 8-8. (a) No Bar or Reef Offshore; (b) Bar or Reef Offshore

One characteristic of waves most evident to an observer standing on shore is the variability in the height of breakers. They generally approach in groups of three or four high waves, followed by another group of relatively small waves. This phenomena is frequently the result of the arrival of two sets of swell(s) (from two different storms or sources), of nearly the same wave period, at the same time. When the crest of the two sets of swell(s) coincide, they reinforce each other and produce waves higher than those of either set. When the crests of one set coincide with the troughs in the other set, a cancelation effect results in smaller waves. By studying the waves, the diver can determine the "*surf beat,*" or frequency of the pattern (Figure 8-9), and time his entry (or exit) to coincide with the period of minimum wave height. Two groups of waves, each with a period of about 12 sec, combine to cause an over "surf beat" period of 2 min. Consequently, under such conditions, a period of minimum wave height can be expected every 2 min.

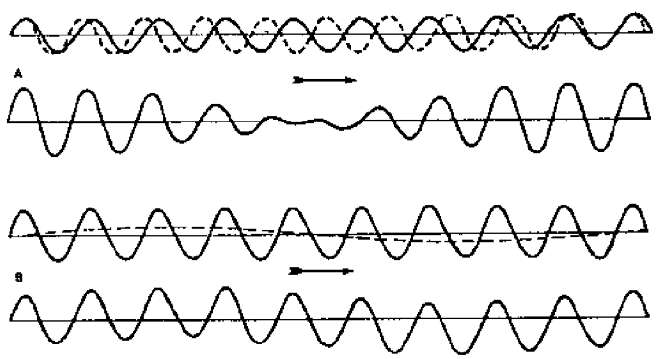


Figure 8-9. Wave Inteference and Surf Beat: (A) Two Waves of Equal Height and Nearly Equal Length Traveling in the Same Direction, Shown with Resulting Wave Pattern; (B) Similar Information for Short Waves and Long Swell (Bowditch, 1966).

Currents

In and adjacent to the surf zone, *currents* are generated by waves approaching the bottom contours at an angle and by irregularities in the bottom. When waves approach the shore at an angle, a longshore current is generated which flows *parallel to the beach* within the surf zone. Longshore currents are most common along straight beaches. The speeds increase with breaker height, decreasing wave period, increasing angle of breaker line with the beach, and increasing beach slope. Speed seldom exceeds 1 knot. As previously discussed, wave fronts advancing over nonparallel bottom contours are refracted to cause convergence or divergence of the energy of the waves. Energy concentrations, in areas of convergence, form barriers to the returning backwash, which is deflected along the beach to areas of less resistance. These currents turn seaward in concentrations at locations where there are "weak points," extremely large water accumulations, gaps in the bar or reef, submarine depressions perpendicular to shore, etc. and form a *rip current* through the surf (Figure 8-10).

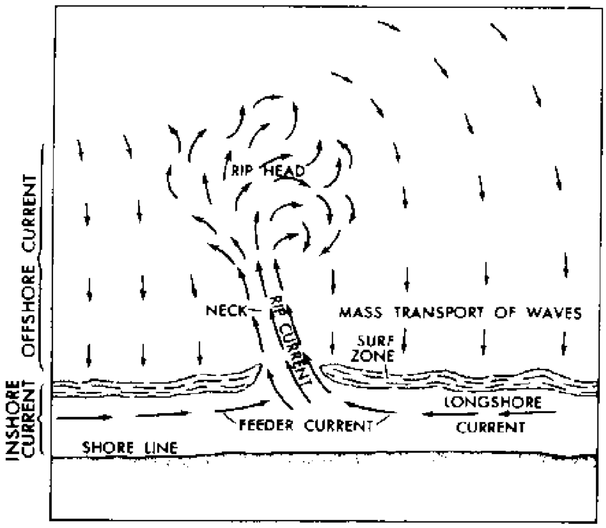


Figure 8-10. Nearshore Current System (Baker et al., 1966)

The large volume of returning water has a retarding effect upon the incoming waves. The waves adjacent to the rip current, having greater energy and not being retarded, advance faster and farther up the beach. This is one way to visually detect a rip current from shore. The rip may also be transporting large volumes of suspended material, creating a muddy appearance.

The knowledgeable diver will use modest rip currents to aid rapid seaward movement. An unsuspecting swimmer, when caught in a rip, should ride the current and swim to the side, not against the current. Outside the surf zone the current widens and slackens. He can then enter the beach at another location. The rip current dissipates a short distance from shore.

Most shorelines are not straight features. Irregularities in the form of coves, bays, points, etc. affect the incoming waves, tidal movements, and the resultant current patterns. When preparing for a dive where beach entries and exits are necessary, the diver must take wave approach, shoreline configuration, and currents into account. Entries and exits should be planned to avoid high waves, as on the windward side of points, and to take maximum advantage of current movements. Avoid dives that require swimming against the current. Never undertake a dive from an ocean beach without considering these factors. Hypothetical beach configuration, wave approach, and current diagrams are included in Figure 8-11 to aid the diver in the concepts of planning beach-entry dives.

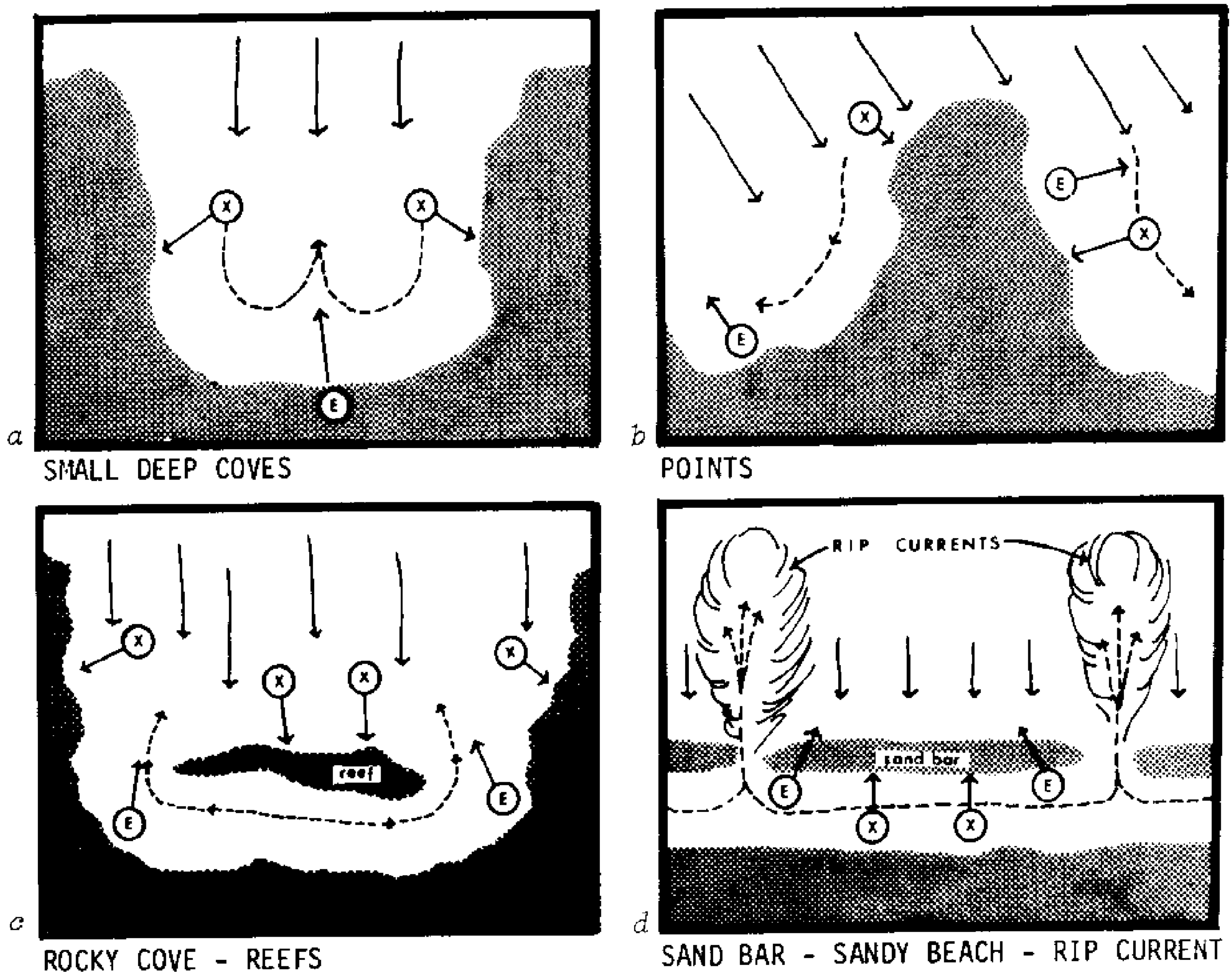
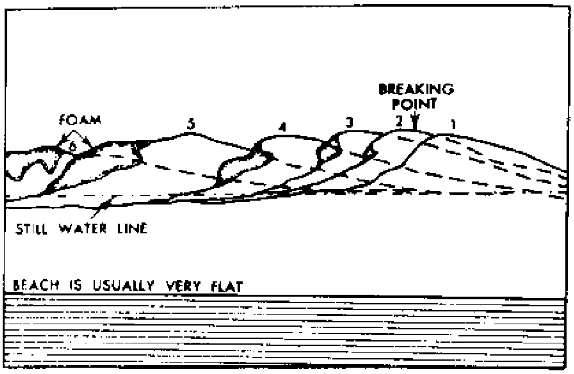


Figure 8-11. Shore Types and Currents: (a) Small, Deep Coves; (b) Points; (c) Rocky Cove, Reefs; (d) Sand Bar--Sandy Beach--Rip Current (E = Entry; X = Exit)

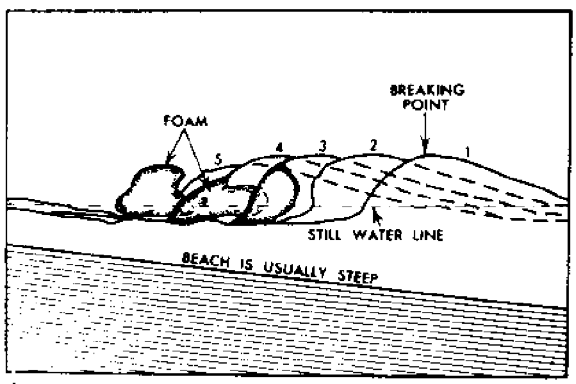
For further information on waves and wave-associated currents, refer to Bascom (1964), King (1960), Russel and MacMillan (1953), and Smith (1970 a, b).

Sand Beach Entry

The width of surf zone and the severity of the breaking waves will be influenced significantly by the slope of the beach. On a *gradually* *sloping beach* the surf zone will be wide since the wave will break, re-form, and break again (Figure 8-12 a). The diver must observe the wave pattern and surf beat in order to time his movement into the surf zone. The best technique for entry is usually to get completely outfitted (including fins), select the best time (least wave height), and move into the zone backwards while watching the oncoming waves. As soon as the water is deep enough, the diver should start swimming. He must swim under the oncoming waves, not attempt to swim over them. A diver should not stand up and face an oncoming wave. If a float is used, it should be towed, not pushed into the waves.



a GENERAL CHARACTER OF SPILLING BREAKERS



b GENERAL CHARACTER OF PLUNGING BREAKERS

Figure 8-12. Breakers: (a) Spilling; (b) Plunging (Baker et al., 1966)

The weight of the equipment, the shift of the normal center of gravity, the restriction of the diving suit, the cumbersome fins, and the fogginess of the mask are all factors which complicate entries through surf. A diver can compensate for the shift in center of gravity and the weight of the tank by moving with his knees slightly bent, feet apart, and leaning slightly forward. When moving, the diver should slide his feet along the bottom and not attempt to take big steps. If a diver falls or is knocked down, even in shallow water, he should not attempt to stand and regain his footing. He should conserve his energy and swim or crawl to deeper water (or back to shore).

A high surf on a *steeply sloping beach* is extremely dangerous for a diver in full equipment. The waves will break violently directly on the beach, with a very narrow surf zone (only a few feet wide) (Figure 8-12 b). A diver wearing fins may be up-ended by the force of the water running down the steep slope after a wave has broken. The diver must evaluate both the shoreline and the surf conditions to determine if safe entry is possible. Under severe conditions, the best judgment may be to abort the dive. To make the entry, the diver should move as close to the water's edge as possible, select the proper time (smallest wave), and move into the water and under the oncoming wave *as soon as possible.* On steeply sloping beaches in Hawaii, divers sometimes elect to carry their fins through the surf instead of wearing them (John Frederick, personal communication). This method allows rapid entry and better footing while entering the surf. Otherwise the diver may be up-ended by the backrush of water acting on his fins. Once beyond the surf zone, the diver dons his fins. Prior to entry, the diver using this method must inflate his buoyancy compensator (or lifejacket) in order to be slightly *positive buoyant* when he gets beyond the surf zone so he can put on his fins. However, an entry *without fins is not recommended.* If local conditions are such that an entry with fins is not possible, then the entry without fins must be made *with considerable discretion* and a great deal of caution. A fully equipped SCUBA diver overweighted and caught in the surf zone without fins is virtually helpless. The diver should select another entry location rather than attempt entries through surf without fins.

When exiting through surf, the diver should stop just seaward of the surf zone and evaluate wave conditions. The exit should be timed so that the diver rides the back of the last large wave of a series as far up the beach as possible. At a point where the diver can stand, he should turn his back toward the beach, face the oncoming waves, and move toward the beach with his body positioned to retain his balance. If the oncoming waves are still at chest level or higher, the diver should dive head first into the wave and stand up as soon as possible when the breaking part of the wave has passed. If the wave is below chest level, the diver should simply lie on top of the wave, keep his feet under him, and ride the wave toward shore. A fatigued diver should not attempt to regain his footing, but ride the wave as high up the beach as possible and crawl out on his hands and knees. On exits through the surf, the float should be pushed in front of the diver and released if necessary to avoid injury or entanglement.

Rocky Shore Entry

When entering surf from a *rocky shore,* the diver should not attempt to stand or walk. A fall can be extremely hazardous. The diver should evaluate the wave conditions, select the backwash of the last large wave of a series, and crawl into the water. The backwash will generally carry the diver through the rocks. Once the diver is moving, he should not attempt to stop or slow down. If the diver retains a prone swimming position and faces the next oncoming wave, he can grasp a rock or kick to keep from being carried back toward the shore. He can then kick seaward after the wave passes. Floats should be towed behind the diver.

When exiting on a rocky shoreline, the diver must stop outside the surf zone and evaluate the wave conditions. Exit toward the beach is made on the backside of the last large wave of a series. As he loses momentum, he should grasp a rock or kick in order to avoid being carried seaward by backwash. The diver should maintain position, catch the next wave, and move shoreward. The diver will finally find it necessary to crawl from the water. When exiting through surf, the diver should always look back in order to avoid surprise conditions.

8.1.4 Tides and Tidal Currents

The *tidal phenomenon* is the periodic motion of the ocean waters in response to the variations in attractive forces of various celestial bodies, principally the moon and sun, upon different parts of the rotating earth (Figure 8-13). On the seacoasts this motion is evidenced by a rhythmic, vertical rise and fall of the water surface called the *tide* and horizontal movements of the water called *tidal currents*. Essentially, tides are long-period waves having a period of 12 hr and 25 min and a wave length equal to one-half the circumference of the earth. The tidal cycle is 24 hr and 50 min.

As just stated, tides result from differences in the gravitational attraction of various celestial bodies, principally the moon and sun, upon different parts of the rotating earth. The force of the earth's gravity acts approximately toward the earth's center, and tends to hold the earth in the shape of a sphere. Although the sun is large in mass, the moon's effect on the earth is much greater because of its proximity to the earth. The moon appears to revolve about the earth, but actually the moon and earth revolve about a common center of mass. The two bodies are held together by gravitational attraction and pulled apart by an equal and opposite centrifugal force. In this earth-moon system, the tide-producing force on the earth's hemisphere nearest the moon is in the direction of the moon's attraction (toward the moon). On the hemisphere opposite the moon, the tide-producing force is the direction of the centrifugal force (away from the moon). The resulting effect on the oceans is that two bulges of water are formed on opposite sides of the earth's surface. The earth rotates on its axis once each day, and one can visualize that it rotates constantly inside a fluid veneer (the oceans). This concept considers the tidal "wave" as standing motionless while the ocean basin turns beneath it. Ideally, most points on the earth should experience two high tides and two low tides daily. However, due to changes in the moon's declination relative to the equator, there is introduced a diural inequality in the pattern of the tidal forces at many places.

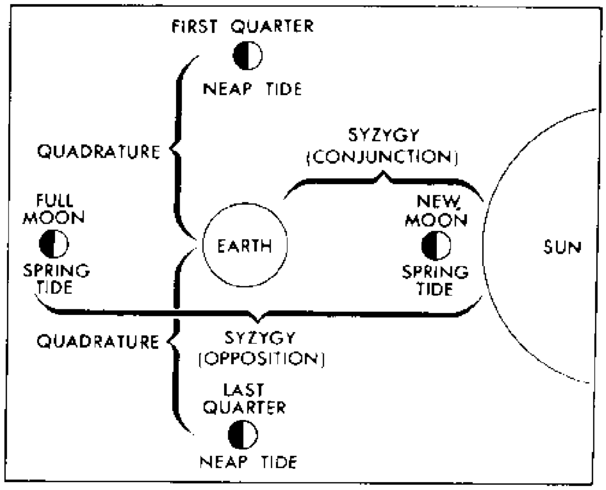


Figure 8-13. Tide Cycle (Baker et al., 1966)

There are similar forces due to the sun, and the total tide-producing force is the resultant of both the sun and the moon, with minute effects caused by other celestial bodies. The sun tides increase or reduce the lunar tides. The two most important situations are when the earth, sun, and moon are aligned (in phase) and when the three form a right angle (out of phase). When they are in phase, the solar tide reinforces or amplifies the lunar tide to cause *spring (high) tides*. Spring tides occur at new and full moon. *Neap (low) tides* occur when the sun and moon oppose each other (out of phase) during the quadratures. The tidal range is further influenced by the intensity of the tide-producing forces (Figure 8-14). When the moon is in its orbit nearest the earth (at *perigee*), the lunar semidiurnal range is increased and perigean tides occur; when the moon is farthest from the earth (at *apogee*), the smaller, apogean tides occur. When these two phenomena coincide, the great perigean spring tides (highest tides of the year) or the small apogean neap tides occur. A slight delay or lag may be noted between a particular astronomic cause and the resultant tide.

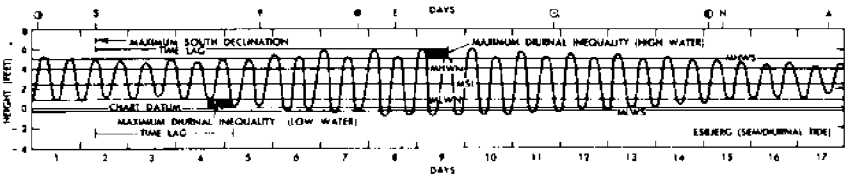


Figure 8-14. Typical Tide Curve (Baker et al., 1966)

Although the tide-producing forces are distributed over the earth in a regular manner, the sizes and shapes of the ocean basins and the interference of the land masses prevent the tides from assuming a simple, regular pattern. The position of the tide relative to the moon is somewhat altered by the friction of the earth as it rotates beneath the water. This friction tends to drag the tidal bulge, while the gravitational effect of the moon tends to hold the bulge beneath it. The two forces establish an equilibrium and, in consequence, a point on the earth passes beneath the moon before the corresponding high tide.

A body of water has a natural period of oscillation that depends on its dimensions. The oceans of the earth's surface appear to be comprised of a number of oscillating basins, rather than a single oscillating body. The response of the basin of water to tide-producing forces is classified as semidiurnal, diurnal, or mixed (Figure 8-15). In a *semidiurnal* type of tide, typical to the Atlantic coast of the United States, there are two high and two low waters each tidal day, with relatively small inequalities in the high- and low-water heights. The *diurnal* type of tide of the northern shore of the Gulf of Mexico has a single high and single low water each tidal day. In the *mixed* type of tide, the diurnal and semidiurnal oscillations are both important factors and the tide is characterized by a large inequality in high-water heights, low-water heights, or in both. Such tides are prevalent along the Pacific coast of the United States.

The tidal range will vary considerably, depending on the configuration of the shoreline, time of month, time of year, wind conditions, etc. On small oceanic islands, the range may be a foot or less. However, along the coasts of major continents, the tidal range is exaggerated at the shore. Estuaries with wide funnel-shaped openings into the ocean tend to amplify the tide range even more. The width of the tidal wave that enters the mouth of the estuary is restricted as the channel narrows; this constriction concentrates the energy and increases the height of the wave. The frictional effects of the sides and bottom of the channel tend to reduce the energy and height. The classic example of this phenomenon is the Bay of Fundy, where the tidal range exceeds 40 ft. Only a few hundred miles away, Nantucket Island has a tidal range of about 1 ft.

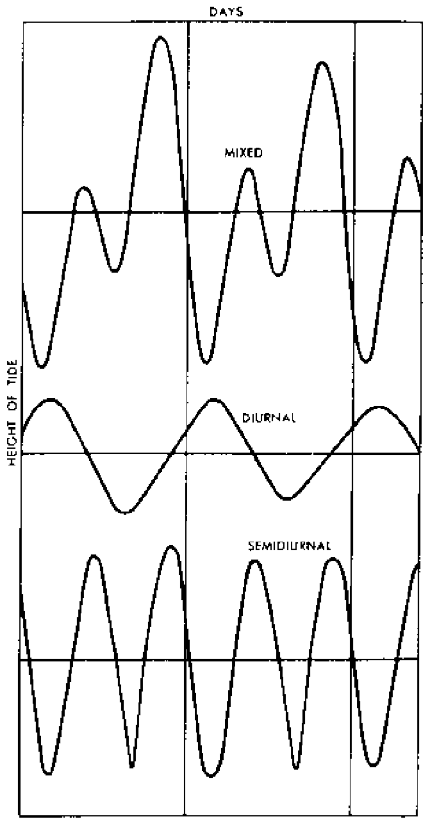
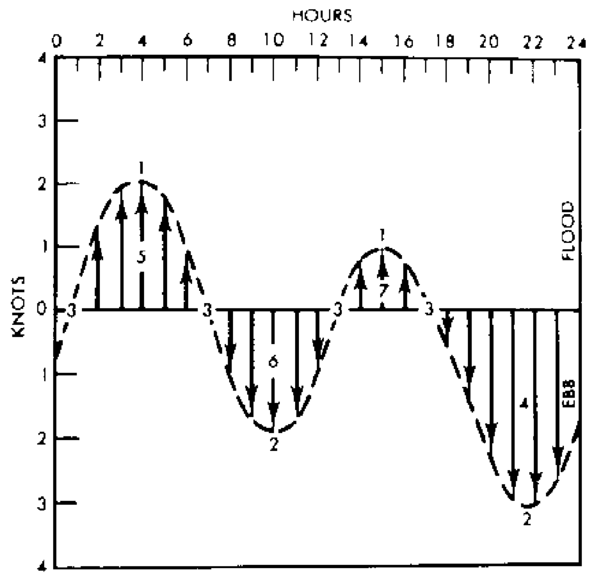


Figure 8-15. Types of Tide Curves (Baker et al., 1966)

Tidal current, the periodic horizontal flow of water accompanying the rise and fall of the tide, is of considerable significance to the diver who must work in restricted bay-mouth areas, channels, etc. Offshore, where the direction of flow is not restricted by any barriers, the tidal current flows continuously, with the direction changing through all points of the compass during the tidal period. In rivers or straits, or where the direction of flow is more or less restricted to certain channels, the current reverses with the rise and fall of the tides. In many locations there is a definite relationship between times of current and times of high and low water. However, in some localities it is very difficult to predict this relationship. Along channels or waterways the relationship will change as the water progresses upstream.

At each reversal of current, a short period of little or no current exists, called *slack water*. During flow in each direction, the speed will vary from zero at the time of slack water to a maximum, called *strength of flood* or *ebb,* about midway between the slack periods. These tidal movements are represented graphically in Figure 8-16. The current direction or set is the direction toward which the current flows. The term "velocity" is frequently used as the equivalent of "speed" when referring to current; however, in proper terminology "velocity" implies direction as well as speed. Tidal current movement toward shore or upstream is the *flood;* the movement away from shore or downstream is the *ebb.*



1. Flood strength; 2. Ebb strength; 3 Slack water; 4. Greater ebb; 5. Greater flood; 6 Lesser ebb; 7. Lesser flood

Figure 8-16. Tidal Current Curve (Baker et al., 1966)

Divers are encouraged to consult local tide tables, confer with local authorities, and make personal evaluations of the water movements in order to determine time of slack water and, consequently, the best time to dive. Tide tables and specific information are contained in various forms in many navigational publications. Tidal current tables, issued annually, list daily predictions of flood and ebb tides, and of the times of intervening slacks.

In some channels or straits the diver will be limited to 10-20 min of safe diving at time of slack water (Figure 8-17). Specific precautions must be taken when working in these areas. Dives must be planned and timed precisely. SCUBA diving may be least desirable. Surface-supplied diving equipment, with heavy weighted shoes, may be required for the diver to work in the currents. The diver should not attempt to swim against the tidal current. If he is caught in a current, he should surface, inflate his lifejacket and swim perpendicular to the current toward shore or signal for pick up by the safety boat.

For further information on tides and tidal currents, refer to Bascom (1964), Defant (1958), and Smith (1968; 1969 a, b).

8.1.5 Wind Currents

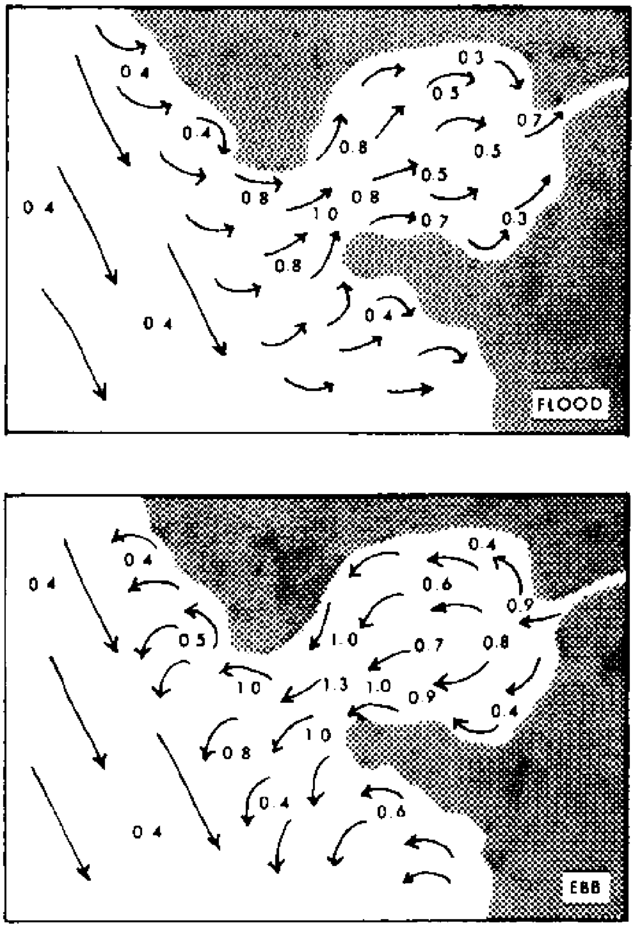


Figure 8-17. Flood and Ebb

The stress of wind blowing across the sea causes the surface layer of water to move. This motion is transmitted to succeeding layers below the surface; however, due to internal friction within the water mass, the rate of motion generally decreases with depth. Although there are many variables, generally a steady wind for about 12 hr is required to establish such a current. A *seasonal* current has large changes in direction or speed due to seasonal winds.

A wind current does not flow in the direction of the wind due to the effects of the rotation of the earth, or Coriolis force. Deflection by Coriolis force is to the right in the northern hemisphere, and toward the left in the southern hemisphere. This force is greater in higher latitudes and more effective in deep water--in general, the difference between wind direction and surface wind. Current direction varies from about 15 degrees along shallow coastal areas to a maximum of 45 degrees in deep ocean. The angle increases with depth, and at greater depths the current may flow in the opposite direction to the surface current.

The speed of the wind-derived current depends on the speed of the wind, its constancy, the length of time it blows, and other factors. In general, about 2 percent or less of the wind speed is a good average for deep water where the wind has been blowing steadily for at least 12 hr.

A number of ocean current flows continue with relatively little change throughout the year. These large-scale currents are primarily the result of the interaction between the general circulation of the atmosphere and the ocean water.

The primary generating force is the wind, and the chief secondary force is the density differences in the water. In addition, such factors as water depth, underwater topography, shape of the ocean basin, land configuration, and the earth's rotation affect oceanic circulation.

8.1.6 Seiches

When the surface of a large, partially enclosed body of water, such as one of the Great Lakes or a bay, is disturbed, long waves may be set up which will rhymically oscillate as they reflect off opposite ends of the basin. These waves, called *seiches,* have a period that depends on the size and depth of the basin. The seiche is a rather common phenomenon not frequently observed by laymen because of the very low wave height and extremely long wavelength. A seiche can be regarded as a standing wave pattern.

In the Great Lakes, seiches are induced primarily by differential barometric pressure changes and, most frequently, winds. For example, a strong wind blowing for several hours along the axis of Lake Erie will drive the surface water toward the leeward end of the lake, raising the water surface there as much as 8.4 ft, and lowering the level at the windward end of the lake. When the wind ceases or shifts, the lake surface will start to oscillate, alternately rising and falling at each end of the lake. This oscillation, which diminishes rapidly in amplitude, has a period of 14-16 hr (Welch, 1935). Lake Erie is particularly subject to seiches because the lake is shallow, nearly parallel with the prevailing winds, and has a basin of fairly regular and simple shape.

In 1954 a severe seiche in Lake Michigan, resulting from both wind and barometric pressure changes, caused an abrupt increase in water level to 10 ft above normal in the vicinity of Chicago. At least seven lives were lost (Hough, 1958; Ewing et al., 1954).

In bays that open to the ocean, seiching is almost always caused by the arrival of a long-period wave train. Once the water is set in motion by the initial wave, seiching continues at the natural period for that harbor or bay. Bascom (1964) discusses the phenomenon of seiching in ocean bays.

8.1.7 Diving in Currents

Currents are caused primarily by the influence of surface winds, changing tides, and rotation of the earth. They are essentially flowing masses of water within a body of water. Divers must always take currents into account in planning and executing a dive, particularly a SCUBA dive. Large ocean currents such as the Gulf Stream of the Atlantic and Japan current of the Pacific flow continuously, although there may be local variations in magnitude and location. Local wind-derived currents are common throughout the oceans and on large lakes.

The current velocity may exceed 2-3 knots. Attempts to swim against this type of current may result in severe fatigue. Sometimes in the Gulf of Mexico, as well as other portions of the ocean, there may be no noticeable current at the surface with a 1- to 2-knot current at a depth of 10-20 ft, or there may be a current at the surface and no current at 10-20 ft down. The following precautions should be observed to minimize the hazards to the diver:

- The diver should always wear a personal flotation device.

- The diver should be in good physical condition when working in currents.

- A safety line at least 100 ft with a float should be trailed over the stern of the boat during diving operations when anchored in a current. Upon entering the water, a diver who is swept away from the boat by the current can use this line to keep from being carried far down current.

- Descent should be made down a weighted line placed at the stern, or, if unavailable, down the anchor line. Free swimming descents in currents should be avoided. If the diver stops to equalize pressure, he may be swept far down current. Furthermore, if a diver has to fight a current all the way to the bottom, he'll be fatigued, a hazardous situation underwater. Ascent should also be made up a line.

- When a bottom current is encountered at the start of the dive, the diver should always swim into the current, not with it. This will facilitate easy return to the boat at the end of the dive. He should stay close to the bottom and use rocks if necessary to pull himself along in order to avoid overexertion. If the diver wants to maintain position, he should grasp a rock or stop behind a rock, not attempt to swim. The same technique should be used by a fatigued diver to rest.

- A qualified assistant should stay on the boat at all times. This will facilitate rescue of a diver swept down current.

For a general review of waves, tides, and currents, refer to Bowditch (1966).

8.2 MARINE LIFE HAZARDS

The life of the marine environment is beautiful and fascinating. Of the thousands of marine animals and plants, relatively few constitute a real hazard to the diver. Although some species are dangerous and may in some instances inflict serious wounds, with a few exceptions marine animals are not aggressive. Generally, it is through the diver's own carelessness that injury results. The diver should respect, not fear, marine animals. He must be able to recognize animals that are capable to inflicting damage, know how to avoid injury, and be able to administer proper first aid in event of injury inflicted by marine organisms.

This discussion will characterize the major groups of marine animals that are known hazards to the diver. No attempt will be made to discuss individual species in detail. Geographically, the discussion will concentrate on the tropical waters of Florida and the Bahamas; however, reference will also be made to animals of the western coast of the United States and the South Seas (including Australia's Great Barrier Reef). Divers are encouraged to consult with local authorities regarding marine hazards whenever they travel to unfamiliar diving areas.

For convenience, the marine animals will be divided into the following categories:

1. marine animals that sting;
2. marine animals that abrade, lacerate, or puncture;
3. marine animals that bite;
4. marine animals that have venomous bites;
5. miscellaneous hazardous marine animals.

8.2.1 MARINE ANIMALS THAT STING

Most marine animals that inflict injury by stinging their victim belong to the phylum Coelenterata. This phylum includes about 10,000 species in three major classes: Hydrozoa (hydroids, fire coral, and Portuguese man-of-war), Scyphozoa (jellyfish), and Anthozoa (sea anemones and corals). Although all coelenterates have stinging tentacles, only about 70 species have been involved in human injuries. However, over 90 percent of the venomous wounds and stings suffered by divers are from members of this phylum.

Coelenterates are characterized by their unique stinging cells, or nematocysts (Figure 8-18), which are situated in the outer layer of tentacle tissue. This apparatus consists of a trigger hair, which, when touched, actuates a spine, followed by a hollow-thread through which a paralyzing drug is injected into the victim. When a diver brushes against or becomes entangled in the tentacles of some coelenterates, thousands of tiny nematocysts may release their stinging mechanisms and inject venom.

Symptoms produced by the stings will vary according to the species, locality, extent and duration of contact, and individual reaction variations. Symptoms may range from a mild prickly or stinging sensation to a throbbing pain which may render the victim unconscious. The pain may be localized or radiate to the armpit, groin, or abdomen. Local redness may be followed by inflammatory swelling, blistering, or minute skin hemorrhage. There may be shock, muscular cramps, loss of sensation, nausea, vomiting, severe backache, frothing of the mouth, constriction of the throat, loss of speech, breathing difficulty, paralysis, delirium, convulsion, and possibly death.

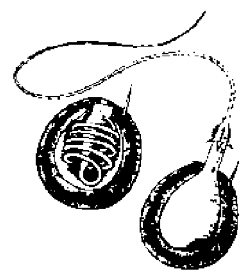


Figure 8-18. Nematocyst (Lermond, 1967)

Stinging Coral

Stinging coral or fire coral (Figure 8-19) is actually not a coral, but a member of the class Hydrozoa. Members of the genus *Millepora* are found among the true corals in warm waters throughout the tropical Indo-Pacific, Atlantic, Red Sea, and Caribbean. Common Florida and Bahamas species are *Millepora complanta* or *Millepora alcicornis* which have a characteristic tan-colored, bladed-type growth with lighter (almost white) upper portions. *Millepora* may appear in a bladed growth form or an incrusting form over rock surfaces or on the branches of soft corals such as alcyonarians. The *Millepora* zone of the outer Florida Keys reefs ranges from 10 to 25 ft deep.

Contacts with *Millepora* are relatively common, with symptoms generally limited to a stinging sensation and reddening of the skin.

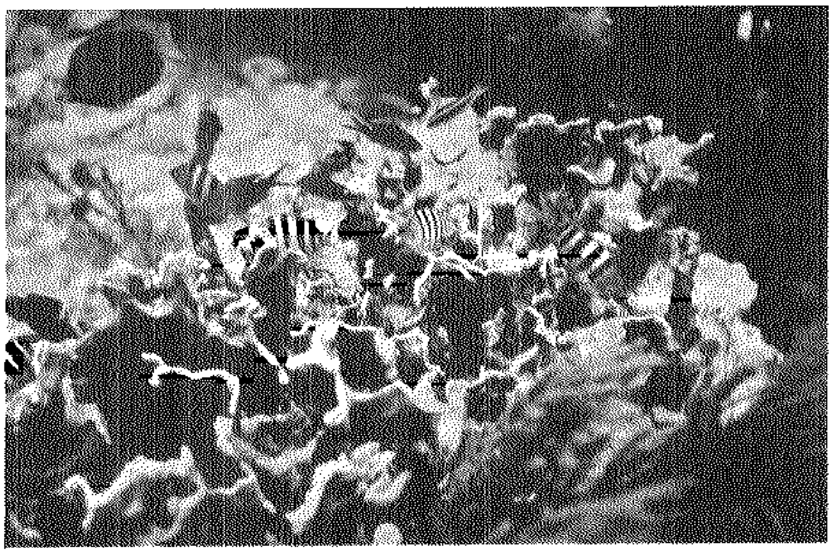


Figure 8-19. Stinging Coral (Photo by Somers)

Portuguese Man-of-War

The *Portuguese man-of-war (Physalia physalis)* (Figure 8-20) is often mistaken for a jellyfish. This hydroid, also called blue bottle, floats on the water's surface in all tropical oceans and the Mediterranean Sea. It appears as a blue transparent jelly-like mass with tentacles bearing large numbers of nematocysts trailing several feet down into the water. A single tentacle may have as many as 75,000 nematocysts. The Portuguese man-of-war drifts with the currents and may be found in localized large concentrations. This hydroid, producing a cobra-like toxin, has been responsible for many injuries in Florida and Bahama waters, with symptoms ranging from minor irritation to shock and respiratory arrest. Other species that produce similar injuries include the *Velella velella* (purple sail) and *Porpita umbella*.

Jellyfish

The class Scyphozoa includes the large, bell-shaped medusae, having eight notches on the margin, and many other species that constitute potential dange for the diver. The *sea wasp* (Figure 8-21), represented

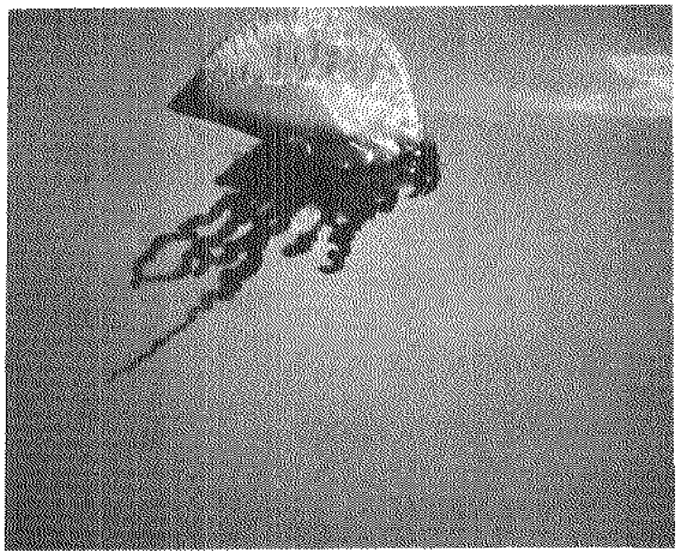


Figure 8-20. Portuguese Man-of-War (Photo by Bruce Higgins)

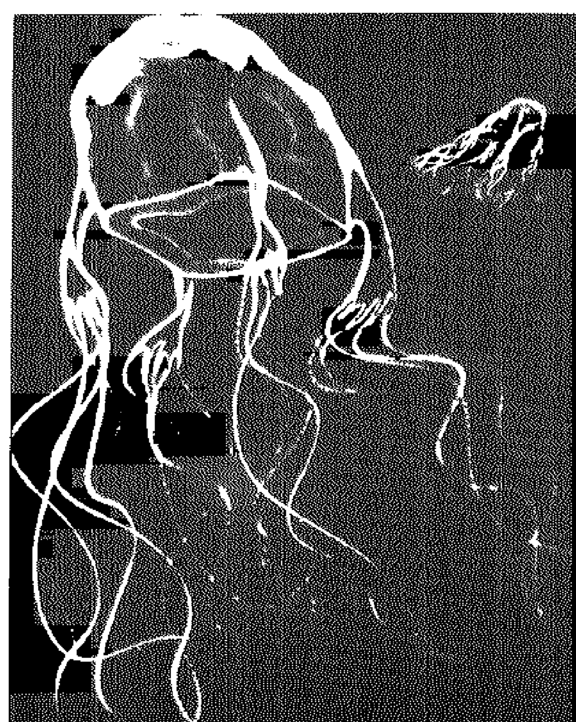


Figure 8-21. Sea Wasp (US Navy, 1970)

by several species, including *Chiropsalmus quadregatus* and *Cheronex fleckeri,* is one of the most lethal venomous marine animals known to man. It is an especially dangerous inhabitant of Australian and Philippine areas, and the Indian Ocean. Stings of the sea wasp have been responsible for a large number of human deaths in Australian waters. Death may follow in 3-8 min after contact. (See the section on first aid which follows.)

Less dangerous, but still painful, are the stings of the sea nettle (e.g., *Dactylometra quinquecirrha*) and the sea blubber (e.g., *Cyanea capillata*). The sea nettle is a widely distributed form which has been found as far north as New England coastal waters, as well as in all tropical sea areas. Sea blubbers inhabit areas from the north Atlantic and Pacific oceans to the Arctic Ocean.

Sea Anemones and Corals

The sea anemones and corals include venomous members which may produce sting symptoms when contacted. The sponge fisherman's disease, for example, has been found to be caused by the tentacles of very small sea anemones which adhere to the sponge, not the sponge itself. Although some forms of coral produce only lacerations, others such as elk horn coral (*Acropora palmata*), which inhabits the Florida Keys, Bahamas, and West Indies, produces added reaction by means of stinging cells.

Preventive Measures

Rubber suits or tight-fitting coveralls have proven to be useful protection. However, avoidance of contact with the tentacles is important. Divers must be able to identify the dangerous species. They should also avoid detached tentacles floating in the water and dead jellyfish found on the beach, since the nematocysts may remain potent for some time.

First Aid for Marine Life Stings

The injured area should immediately be flushed with *sea water* and cleaned of debris. Some authorities suggest liberal use of a solution with high alcohol content (e.g., rubbing alcohol) instead of sea water since it immediately inactivates the nematocysts. Formalin is also effective. Never use fresh water or rub the area with sand; these procedures will cause discharge of more nematocysts. Next, the tentacles that didn't rinse off must be carefully removed with a towel, stick, knife blade, etc. These residual tentacles may also be removed by coalescing them with a drying agent (e.g., flour, baking soda, talc, etc.) and then scraping them from the skin with a thin knife blade.

After tentacles have been removed, neutralize the toxins by applying ammonia, baking soda solution, alcohol, formaldehyde, or a special neutralizing compound. These solutions will also inactivate undischarged nematocysts. Leave this solution on the injured area for 2-3 min. The area should then be thoroughly scrubbed with an antibacterial soap, dried, and an analgesic-antihistamine ointment applied. Observe the victim for general reactions and shock. Seek immediate medical attention if serious symptoms appear. Victims of sea wasp stings must receive medical attention as soon as possible. A special sea-sting kit, which contains toxin neutralizer swabs, antiseptic soap, gauze scrub pads, and an analgesic-antihistamine ointment, has been developed by S. Harold Reuter, MD, and is currently marketed by Dacor Corporation, Northfield, Illinois.

The Commonwealth Serum Laboratories developed an antivenin for stings of the sea wasp, and sublethal stings have been successfully treated. Currently Australian scientists are conducting tests of a toxoid that will provide immunization against the sting. Immunization is required periodically.

8.2.2 Marine Animals that Abrade, Lacerate, or Puncture

A number of marine organisms cause abrasions, lacerations, or punctures when contacted by the diver. Some of these organisms possess venom injection structures and may cause serious complications.

Coral

Wounds inflicted by contact with stony coral (Figure 8-22) are an ever present annoyance to divers working in the tropics. The sharp calcareous edges produce wounds which are generally superficial but notoriously slow to heal. Coral cuts, if left untreated, may become ulcerous. Sting cells may further complicate conditions. The initial effects of coral poisoning are pain and an itching sensation in and around the wound accompanied by reddening and welt formation in the surrounding areas. Secondary infection is common.

First aid involves prompt removal of debris and cleansing of the wound with antibacterial soap. Elevation of the involved limb is strongly recommended. For severe wounds or if complications appear, seek immediate medical attention. Divers are encouraged to wear canvas or leather gloves and diving suits or cloth coveralls for protection when working in the vicinity of coral.

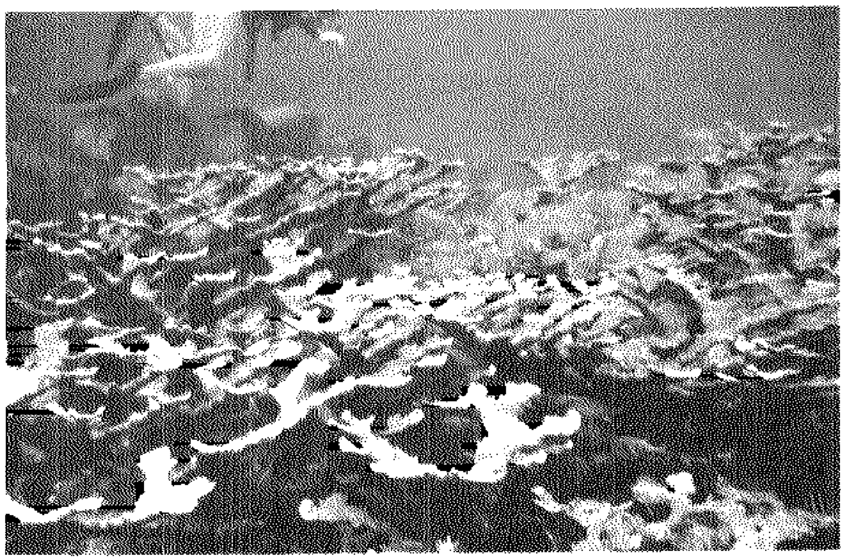


*Figure 8-22. Elk Horn Coral (*Acropora palmata*) (Photo Taken by Somers Near Freeport, Grand Bahama)*

Barnacles

Barnacles, a marine arthropod, in the adult shell form are found attached to rocks, timbers, ship hulls, etc. in and near the intertidal zone (Figure 8-23). These shells are sharp and especially hazardous to divers who must enter the water from rocky shore areas, work on ship hulls near the waterline, or dive around pilings or offshore structures such as oil rigs. An abrasive injury may be further complicated by the presence of hydroids on and among the barnacles. Caution and protective clothing are recommended. First aid measures are the same as for coral lacerations.

Echinoderms

Most members of this group of marine organisms are characterized by radial symmetry and may bear a rigid or semirigid skeleton of calcareous plates or spines on a flexible body way. Included are starfishes, sea cucumbers, and sea urchins. Of all echinoderms, the sea urchins are probably responsible for most injuries to divers.

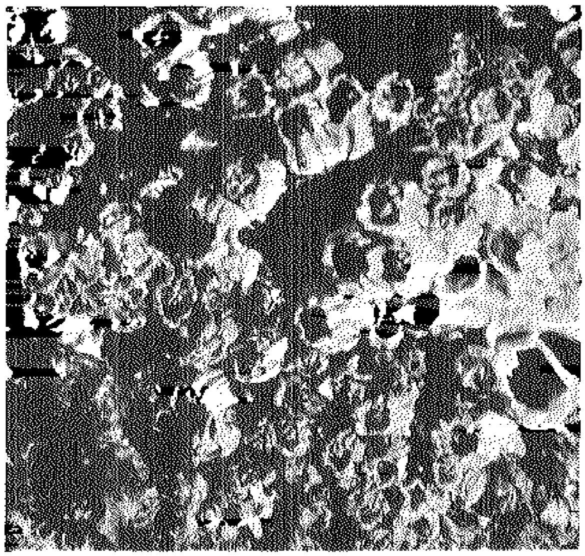


Figure 8-23. Barnacles (Photo by Somers)

Sea urchins (Figure 8-24) occur in large numbers and variety in the shallow coastal waters of the world. The spines, common to all sea urchins, vary greatly from species to species. Most spines are solid, with blunt or rounded tips, and are not venomous. Others, however, are long, slender, sharp, and brittle, permitting easy, deep entrance into the flesh. Because of the extreme brittleness, these spines may be difficult or impossible to withdraw in one piece. Some may secrete a painful, or even deadly venom. In some species, small, delicate, globe-shaped seizing organs called pedicel-

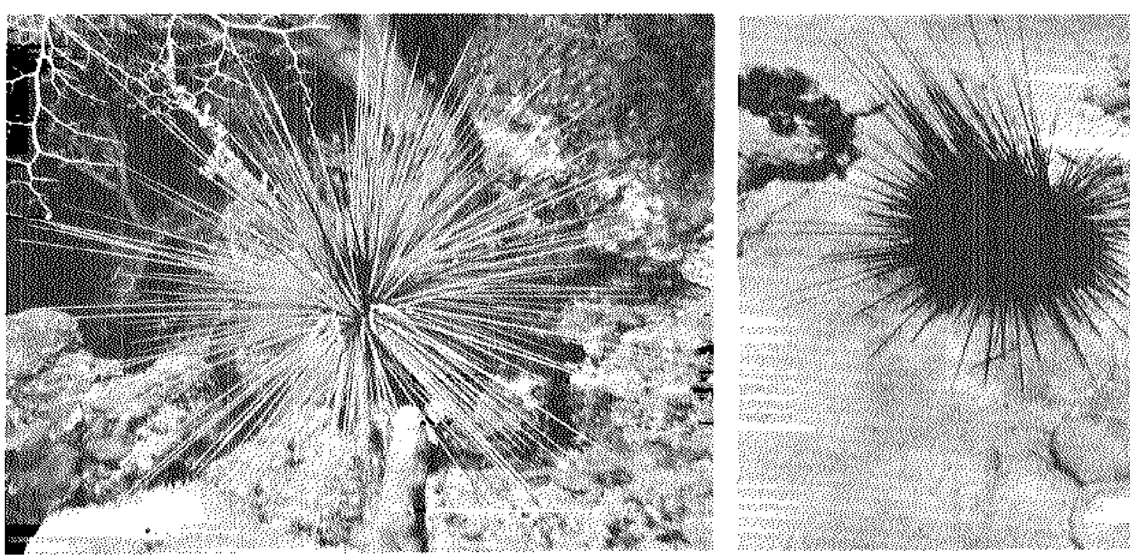


Figure 8-24. Sea Urchins (Photos by Somers)

lariae are distributed among the spines. This globe-shaped head, in at least one type, serves as a venom organ and is armed with a set of pincer-like jaws. One such venomous genus, *Toxopneustes*, inhabits the Indo-Pacific and Japanese waters. Symptoms vary from radiating pain to paralysis and respiratory distress. Fatalities have been reported.

More familiar to the United States diver is the genus *Diadema*, which includes the long-spined or black sea urchin, common to the Bahamas, Florida Keys, and West Indies. These sea urchins with long, brittle spines are not considered deadly but may produce a painful puncture-type wound with redness and swelling. The fragments of the spine will produce a purple discoloration in the area of the wound. In minor injuries, the spines of some species will dissolve with few complications besides pain. However, most spines will cause irritating discomfort of long duration if not removed. These should be removed. These should be removed with a fine tweezer or small needle (sterilized), the area thoroughly scrubbed with antibacterial soap, and a sterile dressing applied. Medication to control pain, inflammation, and infection may be required. Consult a physician immediately if symptoms of infection or other complications appear.

Sea urchins with long needle-like spines should not be handled. Ordinary canvas or leather gloves do *not* afford adequate protection. Divers must exercise extreme caution, especially when working at night.

Cone Shell

The family of marine gastropod Conida (Figure 8-25) is comprised of more than 500 species distributed throughout the tropical seas of the world, but concentrated in the reef areas of the Indo-Pacific. Some species are highly valued by collectors, with *Conus gloriamaris* being worth more than $1000 per specimen. Every species of *Conus* makes a venom peculiar to that species, and most have a fully developed venom delivery apparatus near the shell opening. Radular teeth are thrust into the victim, and the venom is believed to be injected under pressure into the wound. The venom of a given species of *Conus* may only affect certain animals and be totally ineffective on others. Only about six species of *Conus* are considered deadly to man. *Conus geographus* has been officially indicated in human fatalities and other species such as *C. magus* are just as deadly.

The sting of a *Conus* usually produces a numbness, tingling, or burning sensation which may spread rapidly and become particularly pronounced about the lips and mouth. Paralysis and coma may follow. Death from heart failure may result. Unfortunately, most authorities list no specific treatment for cone shell injuries. The first-aider should immediately immobilize the victim and take measures to combat

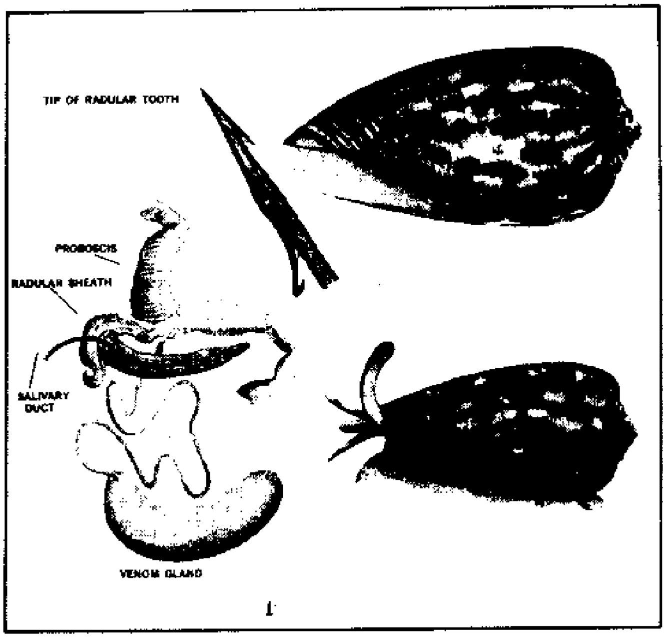


Figure 8-25. Striated Cone (Lermond, 1967)

shock. Promptly scrub the wound with antibacterial soap and water. Suction (using components of a snakebite kit, not by mouth) may be applied to remove poison; a small incision may also be required. Soaking the site of injury in hot water or applying hot compresses for 30 min can be effective in inactivating the venom and reducing pain or other symptoms. Immediate medical attention and hospitalization is generally required.

Specific precautions and ample protection for the hands are necessary when handling cone shells. Avoid contact with the fleshy portion of the animal. Divers must learn to identify dangerous species peculiar to their locality, and specific precautions must be taken in Indo-Pacific waters.

Venomous Fish

Fish that inflict poisonous puncture-type wounds are found throughout the world, but are most common in tropical waters. They are generally nonaggressive, and injury generally results from careless contact with venom-bearing spines, commonly located on or associated with the fins of the fish (Figure 8-26).

The common *spiny dogfish* is a small (up to 3.5 ft in length) shark found along the coast of the Atlantic and Pacific oceans throughout temperate and tropical seas. Two short, stout spines, one situated immediately in front of each dorsal fin, can cause painful wounds. The venom is found in a shallow groove of the spines and enters the victim with the spine. Injury is immediately followed by an intense, stabbing pain of long duration (possibly 6 hr), severe swelling, and redness. Handle dogfish with caution.

Stingrays (Figure 8-27) of many kinds inhabit tropical and subtropical seas at moderate to shallow depths. They are common in sheltered

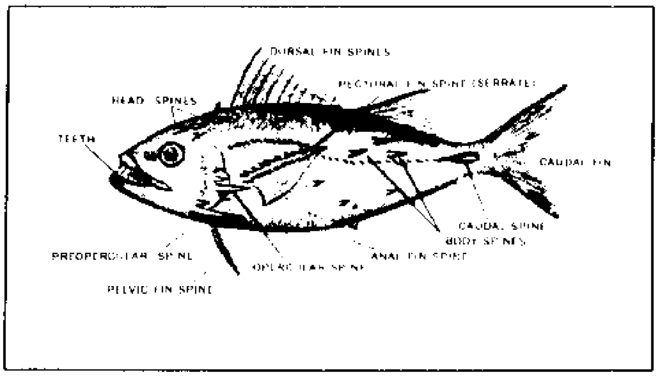


Figure 8-26. Composite Diagram Showing Injury-producing Structures on Body of Fish (Lermond, 1967)

sandy bays and lagoons, where they lie in shallow water on top of or partially buried in the sand or mud. Most rays have a sharp spine near the base of a whip-like tail. Deep, glandular grooves of the spine contain poisonous tissue. The menace is most serious to persons wading or crawling on the bottom in very shallow, protected waters. When stepped on, the ray stikes upward with its tail and may drive the spine deeply into the foot or leg. This usually produces a ragged, dirty wound. The wound usually causes immediate and severe pain. Swelling of the wound area is accompanied by an ashy appearance which later turns red. Symptoms of shock along with fainting, nausea, and weakness may follow, depending on the severity of the injury and the species of stingray. Medical attention is recommended. Wounds in the chest or abdomen are extremely serious and may be fatal. Deaths have been reported. Immediate hospitalization is necessary.

Figure 8-27. Stingray (Photo by Somers)

The diver can avoid contact by entering the water cautiously and shuffling his feet as he moves through shallow water and never lying on the bottom without first looking for rays. Fins and foamed rubber boots offer only limited protection.

About 1000 species of *catfish* are found, primarily in fresh water, and may assume many sizes and shapes. Generally, the body is elongated with oversized head, and the mouth area usually has long barbels or feelers. The skin is usually thick and slimy, without scales, although bony outer plates may exist in some.

Some species have a stiff spine in the front part of the dorsal and pectoral fins. Venom glands are located in the outer skin or sheath of the spine. The venomous spine is equipped with a device which can lock it into an erect position. The wound is generally accompanied by an almost instant stinging, throbbing, or scalding sensation, with radiating pain and numbing; redness and swelling follow. Bacterial infection is possible. Care must be taken to avoid injury when handling venomous species.

Weeverfish (Figure 8-28), of the family Trachinidae, are small but extremely venomous fish found along the *eastern* Atlantic and Mediterranean coasts. Because of an *aggressive* temperament, combined with a well-developed venom apparatus, they present a specific danger to divers. Weevers habitually bury themselves, with only part of the head exposed. With little or no provocation they dart out with fins erect and gill covers expanded and strike at any offending target.

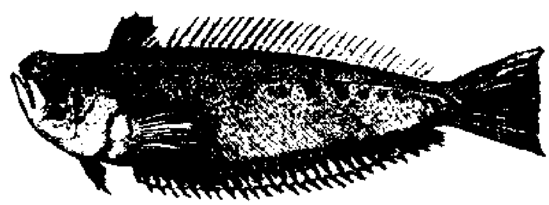


Figure 8-28. Weeverfish (US Navy, 1970)

The dorsal and opercular spines are venomous. This venom is similar to some snake venoms and acts both as a neurotoxin and a hemotoxin. A weever wound normally produces instant burning or stabbing pain that intensifies and spreads. Within 30 min the pain may be severe and the victim may lose consciousness. A large spectrum of symptoms includes headache, fever, chills, delirium, nausea, vomiting, sweating, palpitations, and convulsions.

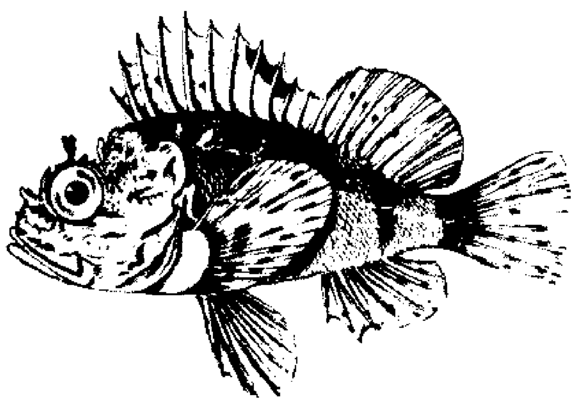
Weevers are commonly encountered while wading in shallow water; care must be taken to avoid contact. Adequate footwear (high-top tennis shoes) may provide some protection. This fish should neither be antagonized into an attack or handled in a careless manner.

The members of the *scorpionfish family* can be found in all tropical and temperate seas. The wound of any of these fish will produce serious results, and a few of the stonefish group, *Synanceja,* may rank with the cobra in the deadliness of the poison secreted. Most species have venomous dorsal spines; some have venomous anal and pelvic spines. These fish are divided into three main groups:

1. scorpionfish, *Scorpaena;*
2. zebrafish, *Pterois;*
3. stonefish, *Synanceja.*

Scorpionfish (Figure 8-29 a, b) inhabit shallow-water bays, lagoons, and reefs--and have also been observed 60-80 ft deep in the waters of the Bahamas. *Scorpaena gutlata* ranges from central California south into the Gulf of California and *Scorpaena plumieri* (and related species) are found on the Atlantic coast from Massachusetts to the West Indies and Brazil. They may be found among debris, rock, or seaweed. Scorpionfish have nearly perfect protective coloration, which enables them to blend into their background and become almost invisible.

Zebrafish (Figure 8-30) are beautiful and ornate fish which swim about coral reefs of the Red Sea and Indo-Pacific seas with their fan-like fins extended in a display fashion. Although extremely beautiful and prized by fish collectors, the fins of this fish contain 18 potentially lethal spines, each equipped with venom.



a

Figure 8-29. Scorpionfish: (a) Sketch (US Navy, 1970); (b) Camouflaged in Natural Habitat (Photo by G. Peter Kelly)

Stonefish (Green, 1966) (Figure 8-31) are encountered in tidepools and shoal areas of the Indo-Pacific. They lie motionless while concealed or partly buried and appear to be fearless. The fish is equipped with as many as 18 spines with enlarged venom glands. In natural concealment, the fish looks like a piece of mud or debris. They present a particularly dangerous hazard to a bare-footed wader.

Other fish which may inflict venomous wounds include toadfish, surgeonfish, dragonets, rabbitfish, and star-gazers. For a detailed account of these fishes, consult Halstead (1959).

Figure 8-29 continued

b

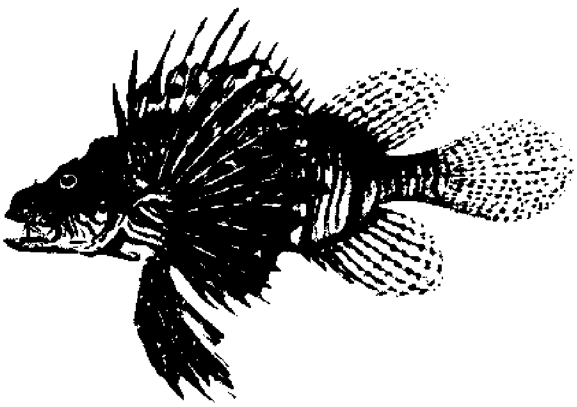
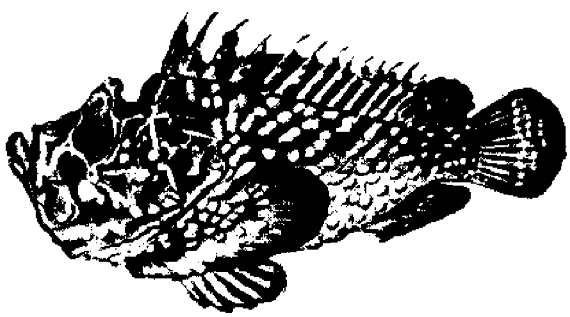


Figure 8-30. Zebrafish (US Navy, 1970)

Figure 8-31. Stonefish (US Navy, 1970)



Prevention of injury from all venomous fish is based on the diver having a healthy respect for the potential serious wound, being aware of the habits of particular species common to the waters in which he is working, and being alert and observant to avoid contact with concealed or camouflaged fish. When diving in an unfamiliar area, it is recommended that divers consult with local authorities.

First aid for venomous fish wounds includes alleviating pain, combating shock and the effects of the venom, and preventing infection. Since unconsciousness is common, the victim should be removed from the water promptly. Carefully wash out or irrigate the wound with cold salt water or with sterile saline. Attempt to remove any remaining portions of the spine sheath. Soak in plain water, as hot as can be tolerated, for at least 30 min. Use hot compresses on areas that cannot be immersed. Heat is believed to destroy the venom. If the injury is of the small, puncture-wound type, make a small incision at the site to encourage bleeding and facilitate irrigation. Visible foreign material should be removed. Apply suction with snakebite kit apparatus, not by mouth, to encourage bleeding. Measures must be taken to combat shock. Medical attention will be needed for further treatment of the wound and prevention of infection.

8.2.3 Marine Animals that Bite

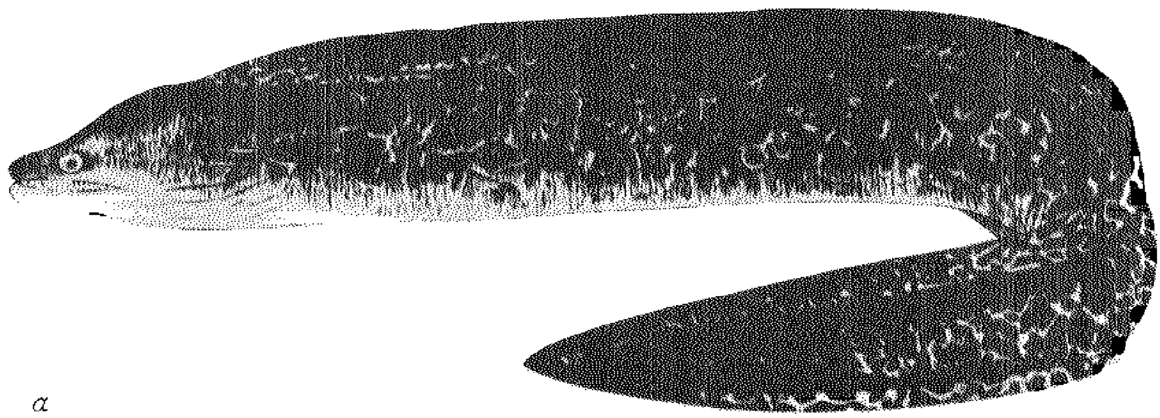
Moray Eels

Moray eels (Figure 8-32), family Munaenidae, are represented by about 20 species and are confined primarily to tropical and subtropical seas, although several temperate-zone species do exist in Californian and European waters. Morays dwell mostly on the bottom in crevices and holes under rock or in coral. They possess powerful jaws with strong, sharp teeth capable of inflicting severe lacerations. The morays seldom attack unless provoked; however, several unprovoked attacks have occurred. Their bite is of the tearing, jagged type.

The diver should exercise due diligence and caution when exploring crevices and holes in areas where morays are known to exist. A moray should not be aggitated. Though some divers successfully hand-feed morays, this activity is not recommended. A moray may become aggressive in defense of its territory.

Barracuda

Barracudas (Figure 8-33) are potentially dangerous fish found widely distributed throughout the tropical and subtropical waters of the



a

b

Figure 8-32. Moray Eel (a) US Navy, 1970; (b) Photo by Somers

Figure 8-33. Barracuda (Photo by Somers)

Atlantic and Indo-Pacific. Their size (which may exceed 6 ft); knife-like, canine teeth; and failure to exhibit any undue fear of man have earned barracudas the false reputation of an extremely pugnacious and dangerous fish that will attack rapidly and ferociously. Although several spearfishermen have been severely injured when attempting to handle speared barracuda, it must also be noted that there are no known *unprovoked* barracuda attacks on divers.

Barracudas are curious-natured fish that may be attracted by excessive movement, bright or colored objects, and, particularly, shiny metal objects that reflect light (i.e., jewelry). It is not unlikely that a barracuda would strike at a speared fish. This is a particular hazard for spearfishermen who carry fish on a stringer attached to their belts. The potential of an accidental encounter with subsequent injury is probably higher in murky water where the barracuda is less likely to see the entire diver and strike at a portion of the diver or the movement which resembles prey.

Prevention of attack appears to be one of respect and caution when diving in waters inhabited by barracuda. Divers should avoid wearing bright or shiny objects. Unnecessary aggitating and hand-feeding of barracuda are discouraged, as is spearing.

Sharks

Sharks (Figure 8-34) are probably the most feared of all marine animals. There are about 250 species of sharks which inhabit all the oceans of the world; however, only a few are considered potentially dangerous to divers and underwater swimmers. There are considerable differences of opinion regarding the potential risk of a shark attack. Cross (1967) gives the following figures on the frequency of shark attacks. During 1959, there were 11 authenticated attacks in the vicinity of the United States, of which three were fatal. By comparison, in the same year, in the United States there were over 400 people killed by lightening and another 1000 injured. In 1960, there were 42 reported shark attacks on humans throughout the world; none were fatal. Of all reported shark attacks, none have involved helmet-equipped divers and only a few have involved SCUBA divers. Almost all attacks have been on swimmers, waders, or persons dangling their arms or legs from surface floats or rafts. Seventy percent of all of the attacks have occurred within 5 ft of the surface and 62.2 percent, within 300 ft of shore.

Statistically, the greatest danger of shark attack exists in tropical and subtropical seas, between 30 degrees north and 30 degrees south of the equator. Particularly dangerous areas are Queensland,

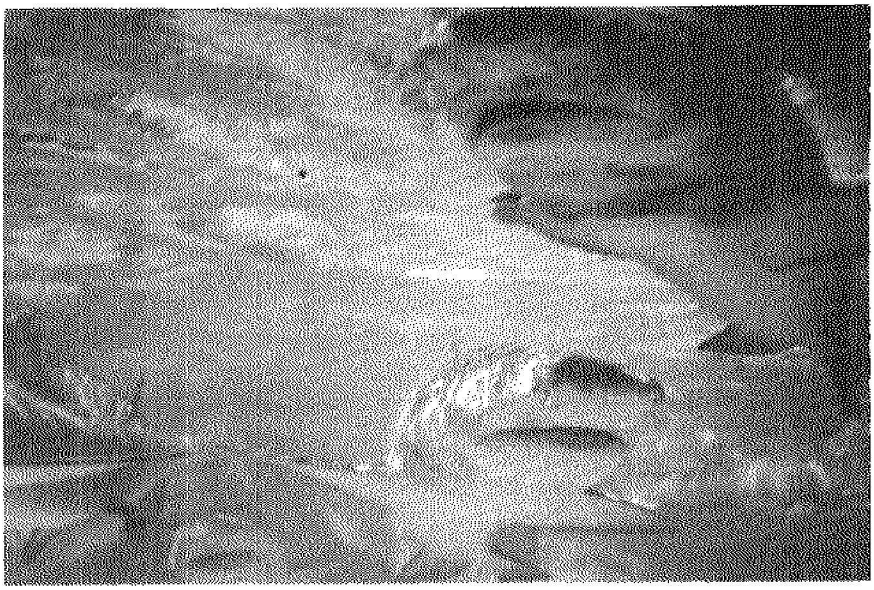


Figure 8-34. Lemon Sharks (Photo by Somers)

Australia, and South Africa. Most attacks have occurred when the water temperature was greater than 70° F, with January as the peak attack month in tropical waters. The greatest risk appears to be between 1500 and 1600 hr (3:00-4:00 pm).

Sharks appear to be attracted by blood (fish or human), flashing lights, colored material, thrashing about, explosions, or unusual noises. The presence of blood highly excites sharks and may radically alter their normal habits. The diver is certainly in most danger if he is injured, bleeding, or carrying speared fish that are bleeding. Sharks apparently have a well-developed sense of smell and will "home in" on blood. They have unique sensory mechanisms which enable them to hear (feel) vibrations from a considerable distance. They are thus more apt to "home in" on surface splashing or underwater noises. Erratic, panic-like movements executed by a frightened swimmer are believed to excite sharks and increase the probability of attack.

In spite of differences of opinion about many aspects of sharks, all authorities agree that *sharks are completely unpredictable.* Although sharks usually seem aloof and quiet, they can become viciously aggressive, and for no apparent reason. Although nurse sharks, sand sharks, and leopard sharks are considered harmless by some divers, attacks have been reported. A University of Michigan scientist was attacked and bitten on the leg during July 1972 while diving in the Florida Keys; the attack was without warning or provocation.

Many opinions have been expressed on how to chase sharks away; however, it has been fairly well established that procedures such as shouting underwater, blowing bubbles, striking on SCUBA cylinders, striking rocks together, or if on the surface, splashing with a cupped hand will not frighten a shark. In fact, it is believed by some authorities that these actions will actually attract sharks. Although several chemical and electronic shark repellants have been developed and used with some success, most authorities feel that there is still no guaranteed effective repellent.

Many divers use a pole (4-8 ft) equipped with an explosive power head for protection or to kill sharks. The power head consists of a chamber and firing device which detonates a 12-guage shotgun shell or 38- to 45-caliber bullet when pressed against the target. This type of weapon is popular in Australia and said to be extremely effective in killing sharks. A certain degree of accuracy is required to hit the shark behind the eyes and dead center over the base of the spine for an effective kill. A wounded shark may be more dangerous, and the blood and thrashing movements may attract more sharks. The power head is also an extremely dangerous weapon, and accidental firing could result in considerable injury to the diver or other swimmers. Some authorities feel that the hazard of the weapon is greater than the hazard of shark attack.

Many authorities advocate the use of a "*shark bully*," constructed to meet personal preference. This defensive weapon consists of a short pole (3-4 ft) made of hardwood, metal, or weighted plastic with a blunt end fitted with a roughened material to prevent slipping on the shark's skin. The best place to strike an aggressive shark is on the snout, or nose. The strike or blow should be as hard as possible. This blow may discourage the shark, and the reactive force pushes the diver aside as the shark passes.

Recently, a *gas injection device*, "shark dart," was marketed by Farallon Industries. The device consists of a CO_2 cylinder contained in a holder; a firing mechanism; a sharply pointed, stainless steel, 5/16-in, hollow needle; and a pole (length varies depending on the the model). The size of CO_2 cylinder also varies with the model. This weapon is effective to 25 ft with a 12-gm CO_2 cylinder, 40 ft with a 16-fm cylinder, and 100 ft with a 26-gm cylinder. A multiple-shot, compressed-air model is also available.

As the shark approaches, the diver thrusts the needle into the abdominal area. The needle easily punctures the skin and subsequently the CO_2 cylinder is punctured by the firing mechanism and the gas is released. This small volume of high-pressure gas entering the shark suddenly displaces the water inside him and forces it to take the path of least resistance. The pressure wave reverberates throughout the shark, blows the stomach out his mouth, and destroys his internal organs. The expanding gas forces the shark to the surface. He is instantly immobilized. For further details, consult McKenny (1972).

When diving in water known to be inhabited by sharks, the diver should observe the following:

- Solo skin or SCUBA diving should be prohibited. Visual sighting and early warning will allow the divers time to leave the water at signs of aggression. One of the two divers is more apt to sight the shark immediately. Also, in the event of an attack, help is immediately available.

- The diver should leave the water immediately if injured or bleeding.

- Diving or swimming in turbid waters should be avoided, if possible. A portion of a diver's leg and fin might have the appearance of a fish on which the shark would feed, whereas a fully visible diver might be discouraging. Moreover, if the diver is aware of the shark's presence and activities, he has a better chance of taking defensive measures, if necessary.

- Light-colored clothing and bright, flashing equipment are more likely to attract sharks and should be avoided.

- Panic must be avoided if a shark is sighted. Half the battle of shark safety is over once the shark is sighted. Rapid movements or immediate ascent to swim on the surface may excite the shark and cause it to move in and investigate. The diver should remain calm and face the shark. If the shark appears to simply be passing by (most of them do), leave it alone. If the shark moves in and is persistent, the diver should stay on the bottom and move slowly and quietly out of the area, preferably toward the boat or other safe place (i.e., shark cage). The diver should not surface, but stay on the bottom as he moves toward his boat position. Safe refuge may be sought in a crevice or behind rocks.

- The diver should never attempt to wound the shark with a spear gun or knife. These actions are virtually useless and may make matters worse.

- Teasing and spearing sharks is discouraged. They are difficult to kill and can react in a fantastic frenzy if hurt.
- Speared fish should never be carried on a stringer attached to the diver.
- A "shark bully" or "shark dart" is recommended for defense in areas of exceptionally large shark populations or where sharks are noted for aggressive behavior. Striking a shark with the bare hand can result in lacerations and bleeding.
- Divers should not dangle arms and legs from surface floats.
- Since the shark is unpredictable, he must be respected and the diver must be prepared to abort the dive in some instances.

The diver should not give up diving just because there are sharks in the ocean. He should learn to respect them, not fear or dislike them. For additional information about sharks and shark attacks, consult Gilbert (1963), Cross (1967), and the US Navy (1959, 1970).

Killer Whale

The killer whale (Figure 8-35), *Grampus orca,* is found in all seas and oceans from the Barent Sea or Bering Straits to beyond the Antarctic Circle. This species is characterized by a bluntly rounded snout; high, black, dorsal fin; white patch behind the eye and a striking jet-black color above the eye; and contrasting white underparts. They are swift swimmers with a reputation of being a ruthless and ferocious killer. Killer whales are reported to hunt in packs and are serious enemies of the seal, walrus, and penguin. In spite of recent notoriety at marine shows of trained killer whales and various published pictures of divers riding them in the ocean, they must still be considered an unpredictable, potentially serious hazard. Divers are encouraged to leave the water immediately when killer whales are sighted in the area.

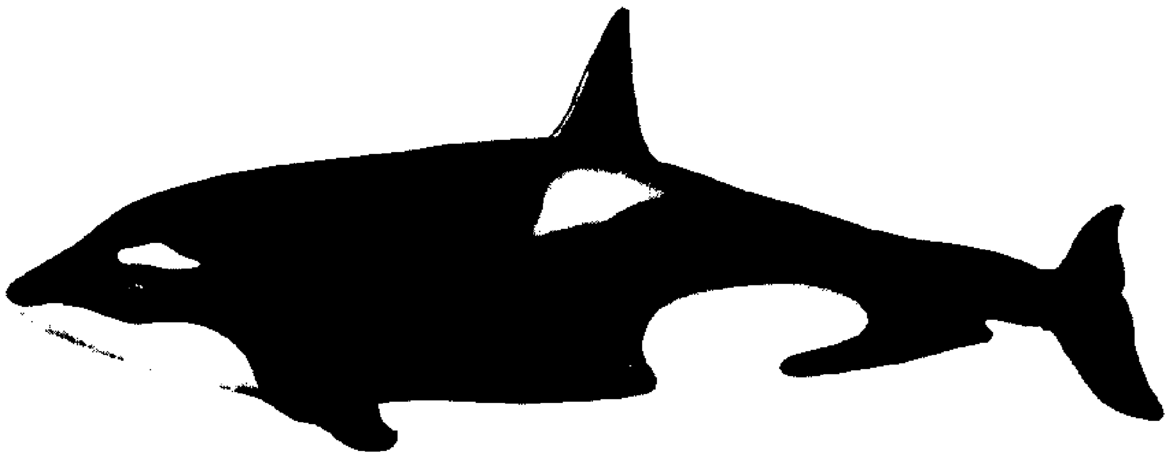


Figure 8-35. Killer Whale (US Navy, 1970)

First Aid

Injuries inflicted by moray eels, barracuda, and sharks are generally severe lacerations with profuse bleeding. First aid for controlling bleeding and subsequent shock are discussed in the section on first aid. Immediate medical attention will usually be required.

8.2.4 Marine Animals that Have Venomous Bites

Octopus

Along with squid, nautilus, and cuttlefish, the octopus (Figure 8-36) belongs to the class Cephalapoda, phylum Mollusca. The octopus has a powerful, parrot-like beak, concealed in the mouth, and, in some species, a well-developed venom apparatus associated with the salivary glands. Because of public notoriety and myth, the octopus is vastly over-rated as a hazard. Actually, the octopus is timid and prefers to stay concealed in holes. In the northwestern United States, skin and SCUBA divers actually hunt larg octopi (up to 20 ft in overall length) and "wrestle" them for sport. Certainly some precautions are required if the octopus must be handled; heavy gloves are recommended. In Florida and the Bahamas the octopi are much smaller, generally not exceeding 2 ft in length.

Figure 8-36. Octopus (Photo by G. Peter Kelly)

The bite is similar for all species and usually consists of two small puncture wounds. A burning sensation with localized discomfort may later spread from the bite. Bleeding is usually profuse and swelling and redness are common in the immediate area. First-aid measures include scrubbing the bite with antibacterial soap and soaking the injured area in hot water for 30 min. Measures to combat shock should be taken and medical attention may be required. Recovery is fairly certain.

Only recently was it discovered that one species of octopus, *Octopus maculosus*, or the blue-ringed octopus, could inflict a *fatal bite*. The blue-ringed octopus is being found in ever increasing numbers off the beaches of South Queensland and other areas of Australia and several fatalities have been recorded. It rarely exceeds a length of 4 in and has dark brown to ocher bands over the body and tentacles. Brilliant blue circles are scattered over the animal. The venom of this octopus is said to carry enough toxin to kill ten men (Deas, 1970; Halstead and Dancelson, 1970).

Sea Snake

About 50 species of *sea snakes* (Figure 8-37) are found, primarily is the tropical Indian and Pacific oceans. At least one species is found on the Pacific coast of Central America and in the Gulf of California. The sea snakes are closely allied to the cobra and form a specialized group adapted by structure and habit to a marine existence. All are poisonous and many are deadly; however, they will generally not attack without provocation and have often been described as docile in habit. Bites usually result from unintentional contact; fatalities are most common in the Gulf of Siam and the Philippine area.

Few sea snakes exceed a length of 4 ft. They are distinguished from land snakes by a paddle-shaped tail. Coloration is dark above and light below with cross-bands of black, purple, brown, gray, green, or yellow. They inhabit sheltered coastal waters, particularly the area near river mouths and may penetrate upstream to the limits of brackish water; a few species are found in fresh water. Sea snakes tend to collect close to shore and among coral reefs in breeding season. The sea snakes generally float on the surface for extended periods of time. Although they are air breathers, they are capable of remaining submerged for long periods.

The bite is usually small, with considerable delay (average of 1 hr) between the injection of venom and the reaction. Some victims fail to notice the connection between the bite and the illness since there is no pain or reaction at the site of the bite. Symptom onset

Figure 8-37. Sea Snake (US Navy, 1970)

progresses from mild to severe, generally beginning with an ill-feeling or anxiety, thickening of the tongue, muscular stiffness, and aching. Later symptoms include shock, general weakness, paralysis, thirst, muscle spasms, respiration difficulties, convulsions, and unconsciousness. According to the US Navy (1970), death occurs in about 25 percent of the cases of sea snake bites.

The diver should avoid aggravating the sea snake and in water known to be inhabited by the snake, he should be alert to avoid accidental contact. Wet-type suits will offer some protection since in the average size snake, the mouth and fangs are relatively small.

First-aid measures include keeping the victim quiet, taking measures to combat shock, and applying a constricting band above the bite if bitten on the arm or leg (this band should not restrict arterial blood flow). Transport the victim *immediately* to the nearest medical facility since antivenin treatment must be started as soon as possible. If possible, accurately identify the offending snake or capture and kill it for later identification. This is helpful for determining treatment procedures. For further details, consult US Navy (1970) and Halstead (1959).

8.2.5 Miscellaneous Hazardous Marine Animals

Sea Lions

Sea lions and harbor seals are normally curious but nonaggressive as they swim about divers. There are reports of playful but potentially damaging "nips" and loss of a swim fin. During the breeding season the large bulls become irritable and may take exception to any intruder. Also, a female may exhibit protective reactions toward a diver molesting her young. One California diver has indicated that a potentially greater danger when swimming with seals is that of being shot with a rifle by a person sitting on a cliff. Some divers wear bright markings on their hoods for this reason.

If bitten by a seal or sea lion, the diver should consult a physician. Some species may transmit infectious diseases.

Giant Clam

The *giant clam, Tridacna gigas* (Figure 8-38), abounds in the reefs of Pacific tropical waters. Specimens may attain a length of 4 ft and weigh several hundred pounds. Some authorities claim that *Tridacna* have trapped divers by closing on a hand or foot with a vice-like

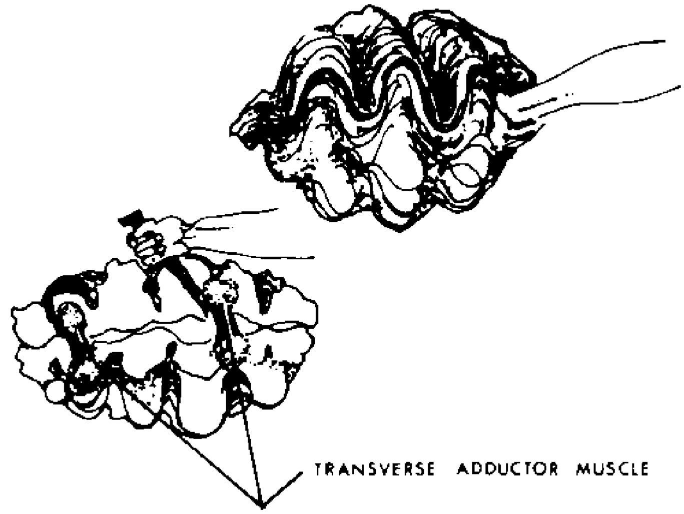


Figure 8-38. Giant Clam (Lermond, 1967)

grip. However, discussions with several scientists who have worked on the Great Barrier Reef of Australia indicate that "trapping of divers by giant clams" is questionable and probably fears are unfounded. In any event, the grip can be released by inserting a knife between the valves and severing the two adductor muscles which hold the valves together. The diver is, however, discouraged from experimenting with his own foot.

Groupers and Jewfish

Some species of giant grouper and jewfish may attain a length of 12 ft and weigh more than 700 lb. They are frequently found around rocks, caverns, and submarine structures such as offshore oil rigs. These fish are not considered vicious, but can be unintentionally dangerous because of their curious nature and huge size. One of the most interesting accounts of an aggressive jewfish is given by Zinkowski (1971).

Annelid Worms

The segmented marine bristleworm (Figure 8-39), *Eurythoe complanata*, possesses tufted, silky, chitinous bristles in a row along each side. Upon contact or stimulation of any kind, the bristles rise on edge as a defensive mechanism. The fine bristles penetrate the skin and are very difficult to remove. This results in a burning sensation, inflammation, and possibly local swelling and numbness. Bristleworms are found in the Bahamas, Florida Keys, Gulf of Mexico, and throughout the tropical Pacific.

Bristles are best removed with forceps, or if exceptionally small, by applying tape to the area and gently removing. After removal, application of ammonia or alcohol will alleviate the discomfort. Divers should avoid contact or take special precautions in handling.

The bloodworm, *Glycera dibrochiata*, is found on the Carolina coast northward into Canadian waters. These worms, up to 12 in. long, may

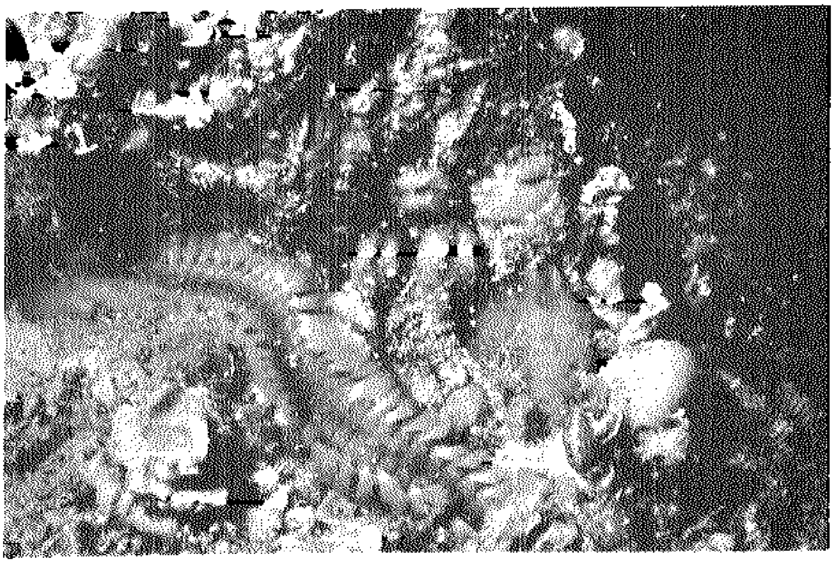


Figure 8-39. Annelid Worms (Photo by G. Peter Kelly)

be encountered under rocks or coral. They possess strong jaws and may inflict a painful bite. Swelling, numbness, and itching follow the bite.

Electric Rays

Electric rays, or *torpedo rays*, grow from 1-6 ft in length and weigh up to 200 lb. They may be found on both the Atlantic and Pacific coasts of the United States as well as other areas of the world. They are shaped somewhat like a normal sting ray; however, their wings are thick and heavy, and their tails are modified for swimming. The giant Atlantic torpedo ray can produce a current of 50 amp at 60 v, enough to electrocute a large fish or knock down a full-grown man. Needless to say, divers must be cautious when approaching or attempting to handle specimens from this group.

Sawfish

Sawfish are members of the ray family that have shark-like shapes and swim by sculling their tails. They are sluggish but powerful and commonly reach a length of 16 ft. The cartilaginous snout is extended in a long, flat "saw," equipped on both sides with sharp scales or denticles which have been enlarged into teeth. Large specimens have been recorded at a length of 22 ft with a 6-ft snout.

The snout is swung from side to side to impale fish. The size and snout make this ray a potential hazard for divers; however, it is not likely to attack unless provoked. Caution is recommended.

Marine Turtles

Recently, divers in the Florida Keys have reported minor injuries resulting from aggressiveness by large *marine turtles*. Several divers were "nipped." Authorities feel that these "nips" were of a playful nature. Still, the size and power of a swimming turtle must be respected by the SCUBA diver.

Paralytic Shellfish Poisoning

Paralytic shellfish poisoning is a well-recognized annual problem on the Pacific coast and occurs occasionally along the Gulf of Mexico. Under environmental conditions of warm weather in summer months (March to November on the West Coast) and an influx of nutrients, the toxic dinoflagellates, *Gonyaulax* sp., undergo a population explosion or "bloom," resulting in the *"red tide."* The waters abound with patches of planktonic algae that turn the water into a variety of colors, including red, yellow, brown, green, black, blue, or milky white.

Unlike many marine animals, mussels and clams ingest and sequestor the poison without damage to themselves. Contrary to popular belief, there is no practical method of distinguishing contaminated (or poisonous) mussels and clams from edible ones. Usual cooking methods do not remove the toxin. In some areas, taking of certain clams and mussels is banned during critical months. Abalone as well as crabs do not feed on plankton nor are their viscera usually consumed; for both reasons, there is no dnager of shellfish poisoning from them. Divers must be especially cautious and consult with local authorities before collecting marine animals for human consumption. All plankton feeders may at times become poisonous.

When consumed by humans, the toxin acts directly on the central nervous system, affecting respiratory and vasomotor centers, and on the peripheral nervous system, producing complete depression. With large doses, respiration may cease instantaneously; with smaller doses, symptoms of nervous system involvement are slow and progressively worsen. Gastrointestinal symptoms (nausea, vomiting, etc.) are less common. Death in severe cases is almost invariably the result of respiratory paralysis and usually occurs within 12 hr. Medical attention should be sought immediately if unusual illness occurs after eating mussels or clams. For details of treatment, consult Halstead (1959) and Anonymous (1971).

Fish Poisoning

Ciguatera poisoning results from eating a wide variety of unrelated fish that contain ciguatoxin (de Sylva, 1968). Apparently only fish, under certain but unknown circumstances, may be involved. In the United States, the only documented species involved is *Sphyraena barracuda*, the great barracuda. Approximately 24 persons are hospitalized annually in southern Florida for ciguatera poisoning from barracuda. There is no seasonal variation, but larger specimens are believed more likely to be toxic.

The onset of symptoms may be delayed for up to 30 hr. Many (about 40-70 percent) victims have a sudden onset of abdominal pain followed by nausea and vomiting, a watery diarrhea, and a metallic taste in the mouth. There is a wide spectrum of other symptoms, from numbness of the lips, tongue, and throat to fever and chilling sensations. If poisoning is untreated, death, from respiratory paralysis, may occur within 10 min, but more commonly after several days. Divers must be cautious about fish they eat. Unusual illness following consumption of fish, especially barracuda, should receive immediate medical attention. The attending physician should be informed that fish has been consumed within the last 30 hr.

Scombroid poisoning is possible from fish tissue that has been exposed to the sun or left to stand at room temperature for extended periods. Within a few minutes of eating the toxic fish, which has a peppery or sharp taste, the victims develop nausea and vomit. Various other symptoms such as intense headache, massive red welt development, and intensive itching follow. Immediate medical attention is indicated.

8.3 Freshwater Life Hazards

Compared to the oceans, freshwater streams, ponds, and lakes have relatively few forms of animal life that present a specific danger to divers. The diver must, however, be aware of those few species that can inflict considerable harm. Shelby and Devine (1962) were among the first to emphasize aquatic hazards to the diving community.

Reptiles

The venomous *cottonmouth* water snake, *Agkistrodon piscivorus,* is found in lakes and rivers south of latitude 38 degrees north. This snake is probably the diver's most serious aquatic hazard. It predominately inhabits stagnant or sluggish water but has been observed in clear and moving water.

There has been a persistant notion that the cottonmouth would not bite underwater; however, Shelby and Devine (1962) documented two fatalities caused by cottonmouth bites. The cottonmouth is considered pugnacious, adamant, and vindictive when disturbed and will attack unprovoked. It does not show fear toward the human as most other aquatic snakes do; its behavior is unpredictable. Attack is more likely to occur in the evening.

Recognition is difficult since its color varies from jet black to green with markings absent or vaguely similar to the *copperhead, Agkistrodon contortrix.* Consequently, in areas where the cottonmouth is known to exist, it is advisable for the diver to regard any snake that does not swim away when encountered as a cottonmouth. The best defense is a noiseless, deliberate retreat. Wet suits afford reasonably good protection, but can be penetrated by larger specimens. Bare hands should be tucked under the armpits. The diver should never attempt to fight since this will probably only result in multiple bites. Although evidence is inconclusive, it appears that the snake will not dive deeper than about 6 ft.

The *timber rattlesnake, Crotalus horridus,* is an excellent swimmer on the surface. Skin divers should be alert and avoid contact.

First aid for venomous snake bites includes:

- Keep the victim quiet and take measures to combat shock.

- If the bite is on an extremity, immediately apply a constricting band about 1 in. above the bite. This band need not be extremely tight like the classic tourniquet. It should be loosened every 30 min for 5 min.

- Apply skin antiseptic over and around the bite and incise (about 1/4 in long and not too deep) with a sharp blade.

- Apply suction with devices available with snakebite kits, if available.

- Acquire immediate medical attention. Antivenin treatment may be required.

Turtles

Three species of aquatic turtles may be hazards to the diver if provoked and mishandled, especially large specimens. Though not venomous, they may inflict a serious, dirty wound. The *alligator snapping turtle, Macrochelys temminchi,* found through the watershed of the Mississippi River, is vicious and aggressive when provoked. It has powerful jaws and sharp claws. The alligator snapper is recognized by three, distinct, keel-like lines running longitudinally the full length of the upper shell. There are also wart-like projections about the head and forelimbs. The alligator snapper is extremely long and muscular, and can strike rapidly by extending the neck.

The *common snapper, Chelydra serpentina,* is smaller and similar in appearance to the alligator snapper. This species is considered by some authorities to be more vicious when provoked than the alligator snapper.

The *softshell turtle* may also inflict a serious wound. Contact with these turtles should be avoided or special precautions taken in handling.

Standard first aid for laceration-type wounds is recommended. Tetanus immunization is recommended.

Alligators and Crocodiles

The *American alligator* (Figure 8-40) has been encountered by divers, but is not known to be aggressive or to cause injury. Yet the potential of injury is present and divers should be cautious. In Central and South America, the *crocodile* may certainly constitute a hazard to divers, and in Africa the crocodile is responsible for many human deaths each year. The *saltwater crocodile* of the coast of Queensland, Australia, is very large (up to 30 ft) and reported to be a vicious aggressor.

Mammals

The *common muskrat* is the only warm-blooded animal that would probably attack a diver in US fresh waters. It attacks only in defense and the wound is usually minor. However, the possibility of rabies is present and serious. It is important for the diver to seek medical advice if bitten and for the animal to be captured, or killed, for laboratory examination. If encountered while diving, the muskrat should not be provoked. If provoked into attack, escape is virtually impossible.

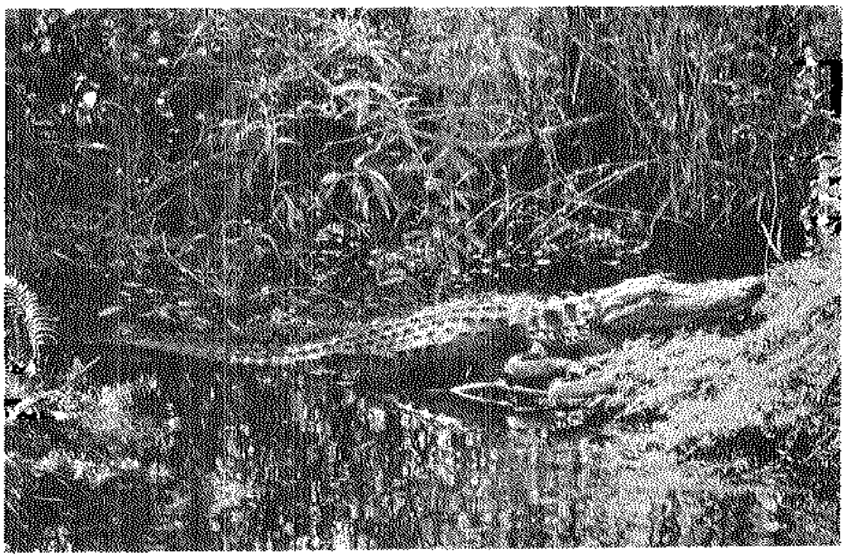


Figure 8-40. American Alligator (Photo by Somers)

Fishes

The only freshwater fishes of noted hazard to divers are the *fresh-water sharks* of Lake Nicaragua in Central America and the *piranha* fish of the Orient and South America. In US waters the only fish capable of inflicting serious injury are those of the catfish family, which are discussed in the section on venomous marine fish, and the *gar*. The gar fish commonly weighs in excess of 100 lb, and if provoked by spearfishermen, has the capability of inflicting wounds with needle-sharp teeth.

The previous discussion has concentrated on the freshwater life hazards of the United States. Certainly, it is only common sense for the diver to consult with local authorities prior to commencing diving operations when working in other parts of the world.

8.4 Other Environmental Factors

8.4.1 Diving in Polluted Waters

Man has polluted his environment. As the contamination of our rivers, lakes, and oceans continues, one certainly must question the quality of the water that thousands of divers from the US and Canada enter each year. Aside from the obvious inorganic pollutants such as mercury, lead, beryllium, antimony, and cadmium, there is a more serious threat. Bacteriological pollution is a fact. Many microscopic bacteria such as typhoid bacillus can be easily detected by health authorities. However, many protozoans are not as easily detected.

Lamirande (1972) reports the death of a diver in Florida from a rarely diagnosed, incurable disease of the central nervous system caused by the amoeba *Naegleria gruberi*. This amoeba has been found in lakes of Florida, Texas, and Virginia as well as several foreign countries. Several deaths due to this amoeba have been recorded in the United States in recent years. The amoeba may lie dormant for many years until nutrient levels in the body of water are concentrated enough to stimulate uncontrolled development. *Naegleria gruberi* may enter the body through the nose, bore into a nasal nerve, and migrate to the brain, where they multiply by the thousands. The result is slow, agonizing death.

Though fatalities of this sort appear to be uncommon today, we cannot predict what will happen tomorrow. Divers must use considerable discretion regarding dives in obviously highly polluted waters. Being aware of this hazard isn't really enough. The only true defense is to fight pollution or accept the fact that acceptable waters for diving (and drinking) may progressively disappear.

8.4.2 Water Temperature

The temperature of the water may vary from 85° F in the Bahamas, to 40° F at 100 ft in Lake Michigan, to 28° F under arctic ice. In temperate and arctic zones, temperature is probably one of the most significant factors to consider when selecting equipment and planning a cold-water diving operation. Diving in cold water and under ice is discussed in Chapter 4.

First let us consider the temperature changes with relation to depth and season. During summer months in lakes and the oceans, the surface waters are warmed by the sun and a temperature zonation (Figure 8-41) is established. In a typical freshwater lake, the upper layer, composed of warmer and less-dense water, is called the *epilimnion* and the lower-most layer of water, which is cold and dense, is called the *hypolimnion*. During late summer in the Great Lakes, the surface water may reach a temperature of 70° F or more; however, at the bottom, in a typical deep lake, the temperature approximates 39.2° F, the temperature of maximum density for fresh water. Between these two water layers is a zone of rapid temperature change, where the temperature gradient is greater than 1° C/m depth. This is the *thermocline*.

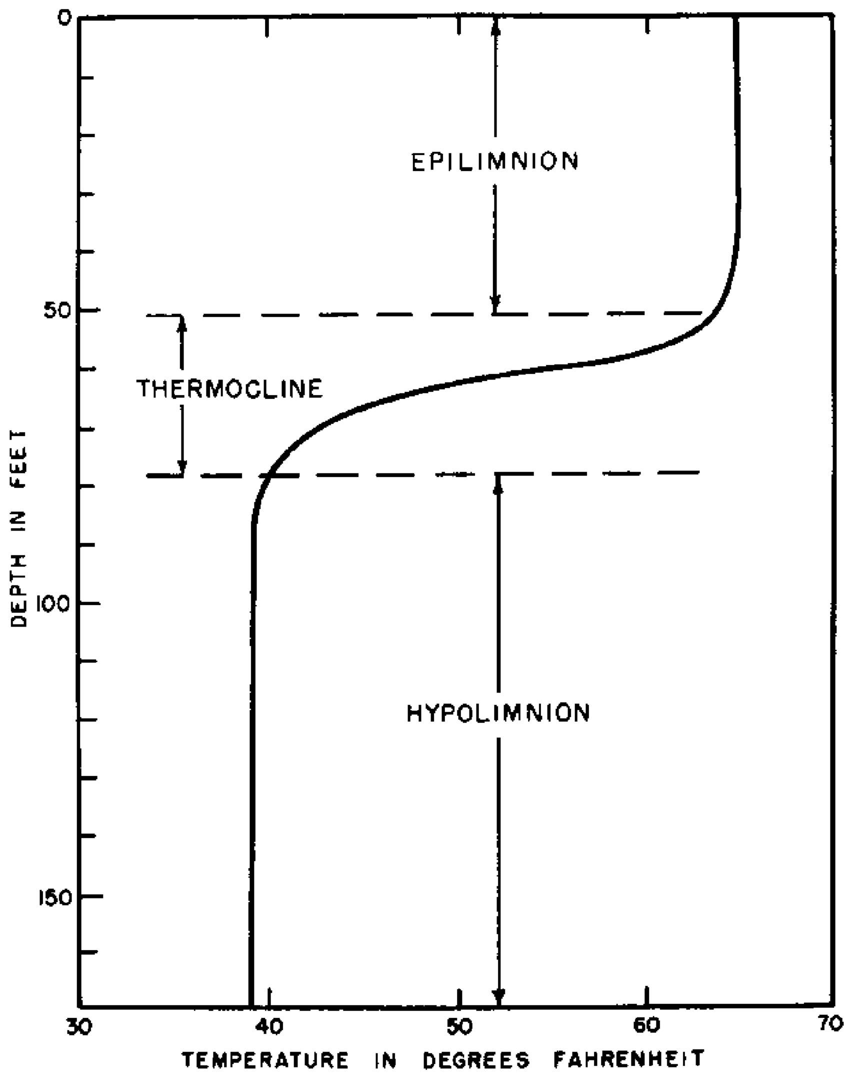


Figure 8-41. Terminology of the Lake Water Temperature Profile (Hough, 1958; reprinted courtesy of the University of Illinois Press)

During the fall months, the lake maintains this well-defined vertical layering until the surface temperature has cooled to about 43° F. At this point, wind-caused circulation is effective enough to destroy the thermocline and mix the entire column of water, producing an *isothermal* (same temperature through entire profile) condition, with the temperature near 39.2° F. This isothermal condition and mixing of the entire water column (*fall overturn*) is maintained until late winter when the lake has cooled to about 35.6° F. Further cooling then produces sufficiently less dense surface water, with a temperature near 32° F. This lighter water forms a stratification sufficient enough to prevent circulation of the lower water, and the water stratification period is established. A *reverse thermocline* is developed.

As the spring sun warms the surface water, it increases to a temperature of 35.6° F and the *spring overturn* begins. This mixing continues until the surface water exceeds 39.2° F, producing a less dense upper layer, and initiating the summer stratification period. See Hough (1958) and Ruttner (1953) for more information on the temperature in lakes.

The temperature structure and changes affect the underwater visibility. During overturn, the visibility is often reduced by material held in suspension by water movements. Surface temperature may be used as an indicator of comfortable surface swimming; however, the Great Lakes diver generally swims in waters of 39.2-42° F at depths of 60 ft or more inthe middle of the summer. The annual temperature cycle in a normal deep-water lake of the temperate zone is given in Figure 8-42.

Surface winds can cause the structure of the water column to change. In the Great Lakes a wind of sufficient duration, velocity, and direction can cause surface waters to flow away from shore and colder bottom waters to replace them. This phenomenon is called *upwelling*. Offshore winds tend to produce upwelling; however, winds paralleling the shore may also cause upwelling, since the Coriolis effect will deflect the flow of water considerably. The Coriolis effect, a deflection force acting on any moving body due to the earth's rotation, will cause deflection to the right in the northern hemisphere and to the left in the southern hemisphere. Some refer to this upwelling as a *tilting* of the thermocline, since warm water frequently depresses the termocline level on the opposite side of the lake. One such upwelling has been observed on the eastern shore of Lake Michigan, and resulted in the establishment of an isothermal water column of 40° F overnight. Similar conditions also exist in the ocean. Upwellings are frequently associated with dramatic population increase in planktonic organisms because of nutrient-rich waters rising from the bottom.

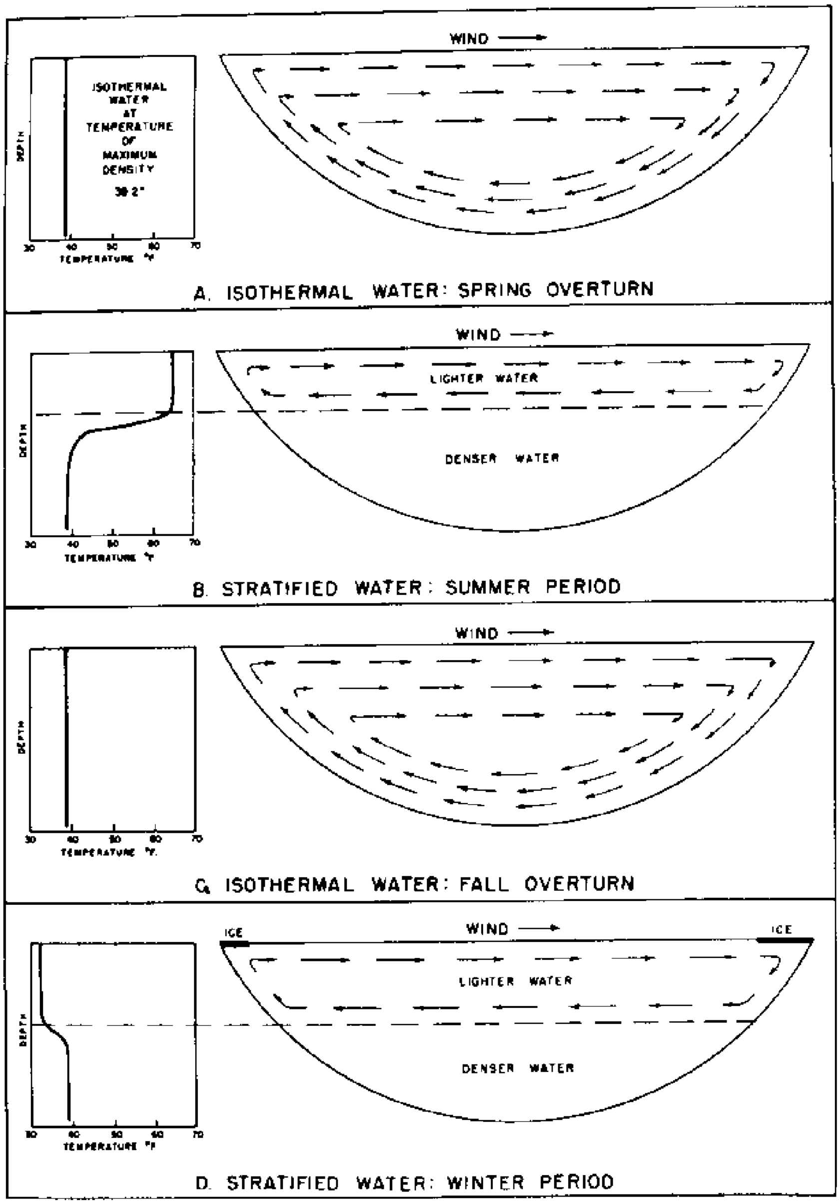


Figure 8-42. Annual Temperature Cycle in Typical Deep Lakes in the Temperate Zone (Hough, 1958; reprinted courtesy of the University of Illinois Press)

8.4.3 Water Transparency

Water transparency or underwater visibility is one of the most important environmental factors that affects the diver's safety and effectiveness. The distance that a diver can see underwater will determine to some extent the diving procedures, the type of equipment used, and the safety precautions necessary. Underwater visibility will range from in excess of 300 ft in open ocean and under antarctic ice to zero in some small lakes or bays. In the Bahamas the visibility is generally in the range of 75-150 ft, whereas the average visibility in the Great Lakes does not exceed 30 ft.

There are a considerable number of factors that influence local underwater visibility. Waters running into lakes and the oceans via streams and rivers may carry a considerable amount of inorganic materials (silts, clay, etc.), erosion products from the land. In lakes, the natural aging by *eutrophication*, or biological enrichment, influences the water transparency. Introduction of nutrient substances into a body of water increases fertility and accelerates the growth of aquatic plankton. Man's activities such as disposal of waste products in lakes accelerate natural processes. Consequently, light penetration and underwater visibility are primarily determined by inorganic material suspended in the water column and biological activity. Seasonal variations in visibility are controlled by biological activity, runoff from the land, and circulation within the body of water. Procedures for working under limited visibility conditions are discussed in Chapter 4.

8.4.4 Marine and Freshwater Plants

Kelps, the great brown algae of northern waters, is considered a potential hazard for divers. West Coast kelps, bladder kelp, are large and some grow to lengths of over 100 ft. A tough holdfast anchors the kelp to the rocky bottom and air bladders float the plant to the surface, where it spreads out to form a thick, floating canopy. The diver, in moving about underwater, may find himself under such a canopy. If he must surface under the kelp, the diver should select the least dense area of growth and extend his hands overhead to part the kelp and make an opening for his head. He can then visually determine the shortest and safest route to open water, submerge (feet first), and swim under the kelp canopy. The surfacing process can be repeated if necessary. Attempting to swim "through" the kelp on the surface usually results in severe entanglement. When swimming in or around kelp, the diver should frequently check projecting equipment to keep free of entanglement. Ribbon kelp is similar to bladder kelp, but tougher.

Surf grass or *eel grass* grows in the surf zone. Though possible, entanglement is not common. The surge may wash it over a diver, causing panic. However, when the surge reverses, the grass will move away and the diver may surface.

A number of *freshwater plants* are found in dense growth in some inland lakes. Divers can become entangled in the plants, and surfacing may be difficult. Panic is the diver's worst foe in a plant entanglement situation. In one recent incident, a Michigan diver became entangled in a weed-covered bottom and surfaced in panicked state. He was treated for an air embolism at The University of Michigan. An entangled diver should stop, relax, and systematically untangle himself. Naturally, the buddy will be of considerable aid.

8.4.5 Weather

Weather is always a factor to consider when planning offshore diving operations in large lakes or the ocean. Divers must be familiar with local weather conditions and monitor weather forecasts. Different areas may have unique weather conditions and the diver must consult with local authorities regarding weather conditions and changes. In some areas, offshore operations from small boats are prohibited by weather and, consequently, wave conditions during certain portions of the year.

When working offshore, abrupt wind and sea condition changes can transform a pleasant day into a nightmare. The diver should not venture too far from shore or from his diving craft when he is aware of the possibility of weather changes. High winds and rough seas can defeat even the strongest swimmer. It is therefore wise to surface periodically and evaluate the weather situation. In the Florida Keys, a squall can sometimes appear seemingly out of nowhere on an otherwise perfect day.

A squall line which appears to be some distance away should be observed for direction of movement, greater development, increased wind velocity, water spouts, etc. If the approaching storm looks severe and is approaching from open ocean, it may be wise to abort the operation and return to shore if you are working from a small boat. In the Florida Keys, however, these squalls approach fast and are generally of short duration. If the squall overtakes the fleeing boat, navigation in poor visibility will be very hazardous.

Under these circumstances it may be wiser to anchor the boat securely and ride the storm out. If the skipper decides to anchor, he must face his boat into the oncoming waves and let out plenty of anchor line; a taut line can snap and the boat will be set adrift.

Following a heavy rain squall, there may be high winds, and the skipper must exercise caution while getting underway again. Choppy seas and murky water may make it difficult to avoid shallow reefs, floating objects, lobster trap lines, etc.

The diver must remember that a wind blowing from land to sea can be very deceiving. What may appear as calm water from shore may be a raging sea at the outer reef. Return to shore into the waves will be difficult.

Serious storms and severe wave conditions can be expected on the Great Lakes in September, October, November, and December as a result of local weather phenomena. This period of instability is discussed by Strong (1968) and relates to the energy system established when cold atmospheric air encounters the air heated by the warmer lake water. The result is sudden storms and high seas. Again the diver is encouraged to consult with local authorities and monitor weather forecasts before conducting offshore operations. Divers are also encouraged to acquire instruction in boat handling and seamanship. Courses are available from the US Coast Guard Auxiliary, sportsman groups, etc.

8.4.6 MAN-MADE STRUCTURES IN OCEANS AND LAKES

The diver must be cautious when working around *jetties* due to the danger or being violently swept into the rocks by waves and/or currents. He should stay on the downwind side of the jetty if possible and avoid diving in strong currents. Visibility generally will be poor.

When diving from *piers* or *wharfs,* the diver must be alert for possible entanglement in fishlines, hooks, lines, etc. Entanglement could be fatal. If entangled, the diver must avoid panic and cut his way out. The diver's partner can play a major role in rescue.

Submerged *shipwrecks* have a certain magnetism for *sport* divers. Some wrecks are extremely hazardous. The possibility of becoming lost inside a ship's hull or entangled in rope, cable, nets, etc. may result in drowning. Old shipwrecks in the Great Lakes are frequently laced with fishnets and in poor visibility the diver may become entangled. Divers are encouraged to take all precautions against getting lost or entangled. As in many facets of sport diving, *the diver must evaluate the situation and determine if the reward is worth the risk.*

Offshore oil rigs of the Gulf coast provide sites for excellent sport diving, scientific research, and, of course, considerable commercial diving activity. These rigs are located at distances of 2-100 miles offshore in waters up to depths exceeding 300 ft. Underwater visibility is generally good all year near the rigs farther from shore.

One of the first safety rules for rig dives is the observance of proper boating procedures. This includes proper size boats when venturing far from shore and monitoring weather. Divers generally tie up to the rig; however, caution must be taken to avoid gas pipes, etc. The rig should be approached from down current and downwind and the boat secured so as to require minimum swimming.

Areas around rigs are populated with vast numbers of both large and small fish and, at least on weekends during the summer, sport divers. Sharks, barracuda, and large jewfish (frequently averaging over 450 lb) are also common. The spearfisherman probably represents the greatest danger to other divers. Divers must be alert for spearfishermen from other parties, or if spearfishing, for other divers. Visibility generally diminishes near or on the bottom, increasing the danger. In addition, the area under and around an offshore rig is virtually a junkyard of cable, pipe, etc. Divers must be cautious to avoid entanglement and/or possible injury.

Frequently divers are attracted to the area around a *man-made dam.* Diving in the vicinity of large dams is discouraged since water moving through open flood gates may suck a diver against the grating, causing injury and/or drowning. Divers have even been swept through overflow discharge channels and pipes on small lakes.

The preceding illustrations represent only a few of man's structures in and under the water. Since the beginning of time, man has disposed of his waste by dumping it into a river, lake, or ocean. Divers, particularly sport divers, find considerable "pleasure" in filtering through underwater garbage. However, there are hazards such as barb wire, sharp metals, etc. that can injure the diver. Caution should be observed, especially when visibility is poor.

8.5 Special Diving Situations

8.5.1 Cave Diving

Diving in underwater caverns is a unique experience that requires specialized equipment and techniques. No other type of diving activity is as dependent on proper techniques, equipment, and teamwork. Most cave diving for research and recreation in the US is in Florida, where there are hundreds of sinkholes and miles of water-filled caverns. The Bahamas also have some excellent caves. During the past 15 years, exploring water-filled caverns using SCUBA has captured the fancy of numerous sport diving enthusiasts. Unfortunately, the per capita mortality rate has also reached the highest of all sport diving activities. Cave diver training should not be undertaken by novices. A considerable amount of open-water experience is the first prerequisite for this activity. Specialized training, equipment, and techniques are discussed by Somers (1971).

8.5.2 Ice Diving

Ice diving is discussed in Chapter 4. It should be emphasized that ice diving is hazardous and should only be undertaken when absolutely necessary. Diving under ice for sport and using SCUBA is discouraged.

8.5.3 River Diving

Diving in rivers is popular in many parts of the United States and Canada. Certainly the most distinct characteristic of rivers is the current. SCUBA divers generally enter the river upstream of their diving location and drift with the current to the desired area. The diver should not attempt swimming against the current, but drift with the current. The current velocity is generally highest in the middle of the river, near the surface and least on the side, near the bottom. Personal flotation equipment (lifejacket, etc.) is mandatory for SCUBA diving in rivers. Most divers also use a surface float.

Surface-supplied divers must operate from securely moored vessels or fixed structures. Special care must be taken when handling tethers. The current will act on the tether forcing the tender to let out more than is necessary. The diver should be placed directly over his working site so that a minimum length of tether is required. If entry into a submerged structure is required, a submerged tender *must* be placed at the entry point to handle the tether. Heavy boots and weights are required to work in river currents. Descent and ascent should be on a heavily weighted shot line.

Many rivers have very poor underwater visibility. Divers must feel their way and be extremely cautious in order to prevent entanglement. Use considerable caution and discretion when working in rivers. Proper procedures to warn ship traffic are mandatory.

8.6 Conclusions

Since the beginning of time, the waters of our planet have stimulated the imagination of man. Under these waters lies an exciting world of beauty and challenge. The underwater explorer and researcher can now, as never before, venture to greater depths and to the most remote corners of the ocean. However, he must be equipped with a basic working knowledge of waves, tides, currents, and marine flora and fauna. The diver must develop a "sixth sense" in the evaluation of environmental conditions in order to plan his dives safely and efficiently. Most divers get into trouble at one time or another by underestimating the potential hazards associated with the underwater environment or by overestimating their physical capabilities and diving skills in coping with adverse currents, waves, etc.

When divers visit unfamiliar areas, they *must* consult with local divers and authorities to gain information on particular marine hazards. For expeditions to remote areas, where medical personnel and hospitals are long distances away, divers must be equipped with special first-aid and medical supplies and specifically be trained in treatment of marine life injuries.

The diver must learn to identify dangerous marine animals and take proper precautions to avoid unnecessary injury. Good physical condition, basic knowledge, common sense, and good judgment are prerequisites for *safe* underwater exploration.

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Appendixes

APPENDIX A

DIVING DUTY MEDICAL EXAMINATION FORM

DIVING DUTY MEDICAL EXAMINATION REPORT

THE UNIVERSITY OF MICHIGAN

To Examining Physician:

This person is an applicant for training (or employment) involving diving with surface-supplied diving equipment or self-contained underwater breathing apparatus (SCUBA). Your opinion of the applicant's medical fitness is desired. The applicant has been requested to complete a medical questionnaire for your convenience (attached). Please bear in mind that diving involves a number of unusual medical considerations. The main ones are as follows:

> Diving involves *heavy exertion*. (A diver must be in good general health, be free of cardiovascular and respiratory disease, and have good exercise tolerance.)
>
> All body air spaces must *equalize pressure* readily. (Ears and sinus pathology may impair equalization or be aggravated by pressure. Obstructive lung disease may cause catastrophic accidents on ascent.)
>
> Even momentary *impairment of consciousness* underwater may result in death. (A diver must not be subject to syncope, epileptic episodes, diabetic problems, etc.)
>
> Lack of *emotional stability* seriously endangers not only the diver but also his/her companions. (Evidence of neurotic trends, recklessness, accident-proneness, panicky behavior, or questionable motivation for diving should be evaluated.)

Suggested Auxiliary Procedures (at Physician's Discretion):

Routine:	urinalysis, wbc, hematocrit, chest film (taken at full inspiration and full expiration).
Divers over 40:	electrocardiogram with step test.
Mixed-Gas Divers:	oxygen tolerance.
Inoculations:	Divers often enter polluted water and are subject to injuries requiring antitetanus treatment. It is strongly advisable to keep all routine immunizations up to date (tetanus, typhoid, diphtheria, small pox, poliomyelitis).

Applicant's Name____

Address____

___________________________________Phone__________________

Date of Birth__________Age____Height_______Weight___________

MEDICAL REPORT

I have examined the applicant and reached the following conclusion concerning his/her fitness for diving:

_____Qualified (I find no defects that I consider incompatible with skin and SCUBA diving.)

_____Disqualified (Examinee has defects that I believe constitute inacceptable hazards to his/her health and safety in skin and SCUBA diving.)

The following conditions should be made known to any physician who treats this person for a diving accident (include medical conditions, drug allergies, etc.):

____

____

____

Signature___________________________MD Date_________________

Address____

____

Remarks:____

____

DIVER'S MEDICAL QUESTIONNAIRE

THE UNIVERSITY OF MICHIGAN

1. Have you had any previous experience in diving? Yes___ No___. Have you done any flying? Yes___No___. If so, did you often have trouble equalizing pressure in your ears or sinuses? Yes___No___. Can you go to the bottom of a swimming pool without having discomfort in ears or sinuses? Yes___No___.

2. Do you participate regularly in active sports? Yes___ No___. If so, specify what sport(s). If not, indicate what exercise you normally obtain.____________________
____

3. Have you ever been rejected for service or employment for medical reasons? Yes___No___. (If yes, explain in "remarks" or discuss with doctor.)

4. When was your last physical examination? Month________ Year______.

5. When was you last chest X-ray? Month________Year_______.

6. Have you ever had an electrocardiogram? Yes___No___. An Electroencephalogram (brain wave study)? Yes___No___.

7. Do you smoke? Yes___No___.

Check the blank if you have or ever have had any of the following. Explain under "remarks," giving dates and other pertinent information, or discuss with the doctor.

8. Frequent colds or sore throat ______

9. Hay fever or sinus trouble ______

10. Trouble breathing through nose other than during colds ______

11. Painful or running ear, mastoid trouble, or broken eardrum ______

12. Asthma or shortness of breath ______

13. Spells of fast or irregular heartbeat ______

14. Chest pain or persistent cough ______

15. High or low blood pressure ______

16. Any kind of "heart trouble" ______
17. Frequent diarrhea. Blood in stools ______
18. Frequent upset stomach, heartburn or indigestion; peptic ulcer ______
19. Stomach or backache lasting more than a day or two ______
20. Kidney or bladder disease; blood, sugar, or albumin in urine ______
21. Recent gain or loss of weight or appetite ______
22. Jaundice or hepatitis ______
23. Tuberculosis ______
24. Rheumatic fever ______
25. Syphilis or gonorrhea ______
26. Broken bone, serious sprain ______
27. Rheumatism, arthritis, or other joint trouble ______
28. Severe or frequent headaches ______
29. Head injury causing unconsciousness ______
30. Dizzy spells, fainting spells, or fits ______
31. Trouble sleeping, frequent nightmares, or sleepwalking ______
32. Nervous breakdown or periods of marked depression ______
33. Dislike for closed-in spaces, large open places, or high places ______
34. Train, sea-, or airsickness ______
35. Any neurologic condition ______
36. Alcoholism or any drug or narcotic habit (including regular use of sleeping pills, amphetamines, tranquilizers, etc. ______
37. Diabetes ______
38. Any serious accident, injury, or illness not mentioned above (describe under "remarks," giving dates) ______

REMARKS

____

____

I certify that I have not withheld any information and that the above information is accurate to the best of my knowledge.

Signature ______________________________

APPENDIX B

BASIC AND ADVANCED RESEARCH DIVER TRAINING COURSES

BASIC SKIN AND SCUBA DIVING COURSE

Medical Examination

The trainee must be medically qualified in accordance with the diving duty medical examination or equivalent (Appendix A). Special medical considerations should be given to divers over 40 years of age.

Watermanship and Physical Fitness

The trainee must hold a current American Red Cross Senior Lifesaving Certificate or equivalent, or complete the following swim skills test without signs of unusual physical fatigue:

A. swim 400 yd in less than 12 min;

B. swim 25 yd underwater without surfacing;

C. surface dive to a depth of at least 10 ft, recover a simulated drowning victim, and tow the victim 25 yd on the surface;

D. stay afloat with minimum effort for 15 min.

Text and Reference Materials

"Research Diver's Manual" (required text)

"US Navy Diving Manual" (reference)

Selected periodical references

Course Duration

The basic course requires approximately 60 hr instruction, including 28 hr of theory, 28 hr of skill training, and 4 hr of qualification dive. The time requirements are dependent on class size, teaching procedures, and many other factors; however, the time listed for each of the following subjects has been found appropriate for a university class of 20 students.

Course Content	Hours
Introduction	2
History of diving, application of diving to research, sport diving, definition of terms, research diving programs, text and literature, diver certifications, medical examination, physical qualifications, watermanship qualifications, general training information.	
Physics of Diving	2
Liquids, gases, pressure, buoyancy, gas laws, gas absorption and elimination, light, sound, mathematical calculations used in underwater work and diving.	
Diving Physiology	1
Physiology and anatomy of the human respiratory and circulatory systems, accessory structures, effects of changing hydrostatic pressures.	
Medical Aspects of Diving	5
Respiratory problems, indirect effects of pressure, problems of descent and ascent, human limitations, environmental problems, miscellaneous problems and their recognition, prevention and first aid for diving accidents, treatment and recompression.	
Marine and Freshwater Environment	3
Physical environment, marine life, freshwater life, first aid for marine life injury, effects of temperature, protective clothing, environmental safety, man-made hazards, diving under adverse conditions, ice and cave diving.	
Physical Fitness	2
Exercise program, testing physical fitness, standards.	
Lifesaving and Water Safety	3
Basic principles: diving safety, self-rescue, assists, approaches, carries, breaks, tows, artificial respiration.	

Course Content	Hours
Skin Diving	4
Basic equipment, skills, physiological hazards.	
Self-Contained Underwater Breathing Apparatus	3
Construction, function, maintenance, selection, accessory equipment, general use, semi-closed circuit, closed circuit.	
Air Compressors and Breathing Air	2
Compressor selection, use and maintenance, filling high-pressure cylinders, breathing air standards, air analysis.	
Use of Self-Contained Apparatus	14
Preparation; fitting, entries, buoyancy adjustments; underwater and surface swimming; drills in overcoming emergency situations due to flooding, leakage, malfunction, entanglement, etc.; dark water drills; share air; free ascent; general use of various regulator breathing systems.	
Diving Equipment	2
Exposure suits, decompression meter, underwater communications, tape recorders, depth indicator, compass, watch, safety flares, cameras, and other accessories.	
Diving Procedures and Techniques	7
Diving procedures; selection of personnel; selection of equipment; planning and organization; decompression and repetitive dive tables; conducting diving operations; basic underwater work; underwater photography; general environmental safety; safety precautions; emergency drills and procedures; lake, ocean, river, ice, and cave diving safety; underwater navigation; diver communication; buddy system; accessory equipment and diving craft; seamanship; recreational diving activities, e.g., spearfishing, etc.	

COURSE CONTENTS	HOURS
Records Log book, accident records, scientific records.	1
Comprehensive Written and Oral Examination Knowledge of physics, physiology, medical aspects, first aid, diving tables, environment, mechanics, techniques, equipment, safety.	3
Practical Evaluation of Skills Performance of various skills in pool and open water.	5
TOTAL	60

WRITTEN EXAMINATION

An applicant for research diver certification must pass a written examination that demonstrates his/her knowledge of the following:

A. Understands the function, maintenance, and use of air diving equipment, including compressors, hoses, helmets, masks, suits, SCUBA, and various accessories.

B. Understands the theory and practice of decompression, and the use of decompression and repetitive dive tables.

C. Knows the cause, symptoms, first aid, and prevention of

air embolism,
near drowning,
carbon dioxide excess,
anoxia,
barotrauma,
nitrogen narcosis,
decompression sickness,
carbon monoxide poisoning,
oxygen poisoning,
respiratory fatigue,
exhaustion.

D. Hazards of breathhold diving.

E. Physics and physiology of diving.

F. Diving regulations and procedures.

G. Near-shore currents, waves, and tides.

H. Dangerous marine and freshwater life, including first aid for injuries.

I. Emergency procedures.

SNORKEL DIVING QUALIFICATION TEST (POOL)

A. Swim 400 yd with mask, fins, and snorkel, alternately swimming on the surface and underwater.

B. Demonstrate acceptable head-first and feet-first surface dives and recover a 20-lb object from a depth of at least 10 ft.

C. Swim 50 yd using a snorkel without a mask.

D. Swim 40 yd underwater with mask, fins, and snorkel without surfacing.

E. Demonstrate ability to enter water with mask, fins, and snorkel by jumping feet first, rolling backward, and rolling forward.

SCUBA DIVING QUALIFICATION TEST (POOL)

A. Demonstrate proper procedure for safe handling of SCUBA, including predive assembly and check, post-dive disassembly and rinsing, and stowage.

B. Enter water with SCUBA by jumping feet first, rolling backward, and rolling forward.

C. Purge water from a mask which is not equipped with a purge valve.

D. Share air with a partner using both single- and double-hose regulators for at least 5 min.

E. Remove and replace SCUBA and mask at a depth of at least 10 ft.

F. Jump into pool while carrying all equipment (including mask, fins, SCUBA, and weight belt) and don all equipment underwater.

G. Give and receive proper hand signals underwater.

H. While wearing SCUBA, rescue and tow a SCUBA-equipped simulated accident victim 50 yd.

I. While wearing SCUBA, swim at least 400 yd on the surface using a snorkel or on back.

J. While wearing SCUBA, make a simulated emergency controlled swimming ascent from at least 10 ft.

K. Perform mouth-to-mouth artificial respiration.

SCUBA Diving Qualification Test (Open Water)

A. Complete two open-water qualification dives to a depth of 30 ft for a duration of at least 30 min.

B. Swim 400 yd in open water in less than 12 min.

C. Share air with a diving partner at a depth greater than 15 ft.

D. Share air with a diving partner while ascending from 30 ft and/or make a simulated emergency controlled swimming ascent from a depth of not less than 20 ft.

E. Demonstrate proper method of entering and leaving water from shore and a boat while wearing SCUBA.

F. Equipped with SCUBA, swim 400 yd on the surface using a snorkel.

Basic Course Certification

To successfully complete the course for diver certification, all trainees must complete each phase of underwater instruction satisfactorily, have a satisfactory attendance record, score 75 percent or better on all examinations, and satisfactorily complete an open-water qualification dive.

Environmental Certification

The diver certificate issued by the University will authorize the holder to dive only in the freshwater environment. To extend the qualification to include marine waters, the diver must complete the following items or their equivalent in the presence of an examiner specified by the diving supervisor or his designated representative:

A. Complete a minimum of three supervised qualification dives in the marine environment.

B. Demonstrate ability to enter and leave the ocean through surf.

C. Demonstrate proper diving techniques for diving in kelp areas.

D. Complete an oral or written examination on diving in the marine environment.

To extend the qualification to include diving in underwater caverns, the diver must complete the following items or their equivalent in the presence of an examiner specified by the diving supervisor or his designated representative:

A. Demonstrate knowledge of selection and use of special equipment required for cave diving.

B. Plan and organize two cave dives.

C. Complete a minimum of six supervised qualification dives in underwater caverns.

D. Complete an oral or written examination on diving in underwater caverns.

ADVANCED RESEARCH DIVING COURSE

The advanced research diving course is designed to qualify scientific personnel and interested students for operational research diving. The training program will consist of both theory and practical aspects of underwater work with supervised diving to 100 ft.

Prerequisites

1. Hold a University, YMCA, NAUI, PADI, or LA County Basic Skin and SCUBA Diving Certificate or equivalent.

2. Hold a current Red Cross Senior Lifesaving Certificate or equivalent.

3. Submit a diver's log book showing that the applicant has completed minimum of 10 dives.

4. Medical examination: see "Basic Course."

5. Interview with the instructor.

6. Diver must supply "approved" equipment: 1/4-in. wet-type suit (complete), weight belt, SCUBA (open circuit), mask, fins, snorkel, lifejacket (inflatable), knife, equipment bag, compass, depth indicator, and watch (desirable).

COURSE DURATION

The course is best conducted during the spring or summer term. Time requirements are as follows:

two 1-hr lecture/discussion periods weekly: advanced diving theory.

one 2-hr pool session weekly (1/2 term).

four open-water diving trips 1- or 2-day weekend; 1/2 term).

CLASS SIZE

Limited to 10 students.

COURSE CONTENT	HOURS
Research Diving Techniques	6
Geological mapping; sedimentation studies; general geological investigation; archaeological techniques; collection and preservation of marine life; biological techniques; marine ecology, etc.; recording observations.	
Underwater Work	6
Basic aspects of surface-supplied diving, search and recovery, salvage techniques, underwater construction, use of tools underwater, and relationship of vessel for underwater work.	
Underwater Photography	6
Cameras and underwater housing, underwater photography techniques, light meters, accessories, stills, motion pictures, lighting, caves, turbid water, recording for scientific data and publication.	
Deep-Diving Techniques	4
Decompression and repetitive dive tables, planning, safety, decompression meter, diving.	
Underwater Communications	2
Systems, use safety, and maintenance.	
Advanced Physiological and Medical Aspects	3
Theory of Mixed-Gas and Saturation Diving	3
Mixed-gases, submersible decompression chamber (SDC), deck decompression chamber (DDC), SDC-DDC combination, USN SEALAB program, Cousteau's Conshelf program, diver-support submersible vehicle with lockout and decompression capabilities, application of mixed-gases and saturation principles to research diving, need for equipment development.	

COURSE CONTENTS	HOURS
Surface-Supplied Diving Lightweight helmet, mask, and hookah: rigging, technique, maintenance, pool practice.	10
Supervised Diving, Underwater Work, and Seamanship	20
TOTAL	60

SURFACE-SUPPLIED DIVING QUALIFICATION TEST (POOL)

A. Demonstrate proper procedure for dressing in and out with free-flow mask, free-flow/demand mask, lightweight helmet, and hot-water suit, and proper maintenance and stowage of equipment.

B. Tend a surface-supplied diver including use of diving signals.

C. Properly enter water and remain submerged for at least 30 min while demonstrating ability to control air flow, swim, and perform tasks such as carrying heavy weights on the bottom of the pool.

D. In a simulated emergency, switch to emergency self-contained air supply, and surface.

E. Release weights and free ascend from a depth of at least 10 ft.

SURFACE-SUPPLIED DIVING QUALIFICATION TEST (OPEN WATER)

A. Demonstrate ability to properly rig all surface equipment for open-water diving, including air supply (primary and emergency), water heater, mask or helmet, and communications units and other support equipment.

B. Plan and organize for a surface-supplied diving operation to 50 ft, including calculation of hose pressure and air requirements and organization of surface personnel.

C. Perform work at a depth of 50 ft for 1 hr.

D. Tend a working diver for 1 hr.

Advanced Research Diver Certification

To successfully complete the course for advanced certification, all trainees must complete each phase of underwater instruction satisfactorily, have a satisfactory attendance record, score 75 percent or better on all examinations, and satisfactorily complete the open-water qualification dives (one dive to 100 ft).

APPENDIX C

TABLES FROM US NAVY DIVING MANUAL (1970) *

TABLE

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*For purposes of standardization, the table numbers in Appendix C are the same as those given in US Navy, "US Navy Diving Manual," NAVSHIPS 0994-001-9010 (Washington, D.C.: US Government Printing Office, 1970).

(FORMERLY TABLE 1-4, 1963 DIVING MANUAL)

TABLE 1-9.—*Decompression procedures*

GENERAL INSTRUCTIONS FOR AIR DIVING

Need for Decompression

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

No-Decompression Schedules

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

Schedules That Require Decompression Stops

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

Variations in Rate of Ascent

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

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

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

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

Repetitive Dive Procedure

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

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

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

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

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

U.S. Navy Standard Air Decompression Table

Instructions for Use

Time of decompression stops in the table is in minutes.

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

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

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

(FORMERLY TABLE 1-5, 1963 DIVING MANUAL)

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

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

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

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

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

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

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

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

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

(FORMERLY TABLE 1-6, 1963 DIVING MANUAL)

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

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

Instructions for Use

I. No-decompression limits:

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

II. Repetitive group designation table:

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

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

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

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

(FORMERLY TABLE 1-7, 1963 DIVING MANUAL)

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

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

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

Instructions for Use

Surface interval time in the table is in *hours* and *minutes* (7:59 means 7 hours and 59 minutes). The surface interval must be at least 10 minutes.

Find the *repetitive group designation letter* (from the previous dive schedule) on the diagonal slope. Enter the table horizontally to select the surface interval time that is exactly between the actual surface interval times shown. The repetitive group designation for the *end* of the surface interval is at the head of the vertical column where the selected surface interval time is listed. For example, a previous dive was to 110 feet for 30 minutes. The diver remains on the surface 1 hour and 30 minutes and wishes to find the new repetitive group designation: The repetitive group from the last column of the 110/30 schedule in the Standard Air Decompression Tables is "J." Enter the surface interval credit table along the horizontal line labeled "J." The 1-hour-and-30-minute surface interval lies between the times 1:20 and 1:47. Therefore, the diver has lost sufficient inert gas to place him in group "G" (at the head of the vertical column selected).

*NOTE.—Dives following surface intervals of *more* than 12 hours are not considered repetitive dives. *Actual* bottom times in the Standard Air Decompression Tables may be used in computing decompression for such dives.

(FORMERLY TABLE 1-8, 1963 DIVING MANUAL)

Table 1-13.—*Repetitive dive timetable for air dives*

Repetitive groups	Repetitive dive depth (ft) (air dives)															
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
A	7	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2
B	17	13	11	9	8	7	7	6	6	6	5	5	4	4	4	4
C	25	21	17	15	13	11	10	10	9	8	7	7	6	6	6	6
D	37	29	24	20	18	16	14	13	12	11	10	9	9	8	8	8
E	49	38	30	26	23	20	18	16	15	13	12	12	11	10	10	10
F	61	47	36	31	28	24	22	20	18	16	15	14	13	13	12	11
G	73	56	44	37	32	29	26	24	21	19	18	17	16	15	14	13
H	87	66	52	43	38	33	30	27	25	22	20	19	18	17	16	15
I	101	76	61	50	43	38	34	31	28	25	23	22	20	19	18	17
J	116	87	70	57	48	43	38	34	32	28	26	24	23	22	20	19
K	138	99	79	64	54	47	43	38	35	31	29	27	26	24	22	21
L	161	111	88	72	61	53	48	42	39	35	32	30	28	26	25	24
M	187	124	97	80	68	58	52	47	43	38	35	32	31	29	27	26
N	213	142	107	87	73	64	57	51	46	40	38	35	33	31	29	28
O	241	160	117	96	80	70	62	55	50	44	40	38	36	34	31	30
Z	257	169	122	100	84	73	64	57	52	46	42	40	37	35	32	31

Instructions for Use

The bottom times listed in this table are called "residual nitrogen times" and are the times a diver is to consider he has *already* spent on bottom when he *starts* a repetitive dive to a specific depth. They are in minutes.

Enter the table horizontally with the repetitive group designation from the Surface Interval Credit Table. The time in each vertical column is the number of minutes that would be required (at the depth listed at the head of the column) to saturate to the particular group.

For example: The final group designation from the Surface Interval Credit Table, on the basis of a previous dive and surface interval, is "H." To plan a dive to 110 feet, determine the residual nitrogen time for this depth required by the repetitive group designation: Enter this table along the horizontal line labeled "H." The table shows that one must *start* a dive to 110 feet as though he had already been on the bottom for 27 minutes. This information can then be applied to the Standard Air Decompression Table or No-Decompression Table in a number of ways:

(1) Assuming a diver is going to finish a job and take whatever decompression is required, he must add 27 minutes to his actual bottom time and be prepared to take decompression according to the 110-foot schedules for the sum or equivalent single dive time.

(2) Assuming one wishes to make a quick inspection dive for the minimum decompression, he will decompress according to the 110/30 schedule for a dive of 3 minutes or less (27+3=30). For a dive of over 3 minutes but less than 13, he will decompress according to the 110/40 schedule (27+13=40).

(3) Assuming that one does not want to exceed the 110/50 schedule and the amount of decompression it requires, he will have to start ascent before 23 minutes of actual bottom time (50−27=23).

(4) Assuming that a diver has air for approximately 45 minutes bottom time and decompression stops, the possible dives can be computed: A dive of 13 minutes will require 23 minutes of decompression (110/40 schedule), for a total submerged time of 36 minutes. A dive of 13 to 23 minutes will require 34 minutes of decompression (110/50 schedule), for a total submerged time of 47 to 57 minutes. Therefore, to be safe, the diver will have to start ascent before 13 minutes or a standby air source will have to be provided.

(FORMERLY TABLE 1-9, 1963 DIVING MANUAL)

TABLE 1-14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet) 130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent time (min:sec)
40	360	0:30													23	23:40
	480	0:30													41	41:40
	720	0:30													69	69:40
60	240	0:40												2	79	82:00
	360	0:40												20	119	140:00
	480	0:40												44	148	193:00
	720	0:40												78	187	266:00
80	180	1:00												35	85	121:20
	240	0:50											6	52	120	179:20
	360	0:50											29	90	160	280:20
	480	0:50											59	107	187	354:20
	720	0:40										17	108	142	187	455:20
100	180	1:00										1	29	53	118	202:40
	240	1:00										14	42	84	142	283:40
	360	0:50									2	42	73	111	187	416:40
	480	0:50									21	61	91	142	187	503:40
	720	0:50									55	106	122	142	187	613:40
120	120	1:20										10	19	47	98	176:00
	180	1:10									5	27	37	76	137	254:00
	240	1:10									23	35	60	97	179	396:00
	360	1:00								18	45	64	93	142	187	551:00
	480	0:50							3	41	64	93	122	142	187	654:00
	720	0:50							32	74	100	114	122	142	187	773:00
140	90	1:30									2	14	18	42	88	166:20
	120	1:30									12	14	36	56	120	240:20
	180	1:20								10	26	32	54	94	168	386:20
	240	1:10							8	28	34	50	78	124	187	511:20
	360	1:00						9	32	42	64	84	122	142	187	684:20
	480	1:00						31	44	59	100	114	122	142	187	801:20
	720	0:50					16	56	88	97	100	114	122	142	187	924:20
170	90	1:50								12	12	14	34	52	120	246:50
	120	1:30						2	10	12	18	32	42	82	156	356:50
	180	1:20					4	10	22	28	34	50	78	120	187	535:50
	240	1:20					18	24	30	42	50	70	116	142	187	681:50
	360	1:10				22	34	40	52	60	98	114	122	142	187	873:50
	480	1:00			14	40	42	56	91	97	100	114	122	142	187	1007:50
200	5	3:10													1	4:20
	10	3:00												1	4	8:20
	15	2:50											1	4	10	18:20
	20	2:50											3	7	27	40:20
	25	2:50											7	14	25	49:20
	30	2:40										2	9	22	37	73:20
	40	2:30									2	8	17	23	59	112:20
	50	2:30									6	16	22	39	75	161:20
	60	2:20								2	13	17	24	51	89	199:20
	90	1:50					1	10	10	12	12	30	38	74	134	324:20
	120	1:40				6	10	10	10	24	28	40	64	98	180	473:20
	180	1:20		1	10	10	18	24	24	42	48	70	106	142	187	685:20
	240	1:20		6	20	24	24	36	42	54	68	114	122	142	187	842:20
	360	1:10	12	22	36	40	44	56	82	98	100	114	122	142	187	1058:20

TABLE 1-14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet) 130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent time (min:sec)
210	5	3:20													1	4:30
	10	3:10												2	4	9:30
	15	3:00											1	5	13	22:30
	20	3:00											4	10	23	40:30
	25	2:50										2	7	17	27	56:30
	30	2:50										4	9	24	41	81:30
	40	2:40									4	9	19	26	63	124:30
	50	2:30								1	9	17	19	45	80	174:30
220	5	3:30													2	5:40
	10	3:20												2	5	10:40
	15	3:10											2	5	16	26:40
	20	3:00										1	3	11	24	42:40
	25	3:00										3	8	19	33	66:40
	30	2:50									1	7	10	23	47	91:40
	40	2:50									6	12	22	29	68	140:40
	50	2:40								3	12	17	18	51	86	190:40
230	5	3:40													2	5:50
	10	3:20											1	2	6	12:50
	15	3:20											3	6	18	30:50
	20	3:10										2	5	12	26	48:50
	25	3:10										4	8	22	37	74:50
	30	3:00									2	8	12	23	51	99:50
	40	2:50								1	7	15	22	34	74	156:50
	50	2:50								5	14	16	24	51	89	202:50
240	5	3:50													2	6:00
	10	3:30											1	3	6	14:00
	15	3:30											4	6	21	35:00
	20	3:20										3	6	15	25	53:00
	25	3:10									1	4	9	24	40	82:00
	30	3:10									4	8	15	22	56	109:00
	40	3:00								3	7	17	22	39	75	167:00
	50	2:50							1	8	15	16	29	51	94	218:00
250	5	3:50												1	2	7:10
	10	3:40											1	4	7	16:10
	15	3:30										1	4	7	22	38:10
	20	3:30										4	7	17	27	59:10
	25	3:20									2	7	10	24	45	92:10
	30	3:20									6	7	17	23	59	116:10
	40	3:10								5	9	17	19	45	79	178:10
	60	2:40					4	10	10	10	12	22	36	64	126	298:10
	90	2:10		8	10	10	10	10	10	28	28	44	68	98	186	514:10
260	5	4:00												1	2	7:20
	10	3:50											2	4	9	19:20
	15	3:40										2	4	10	22	42:20
	20	3:30									1	4	7	20	31	67:20
	25	3:30									3	8	11	23	50	99:20
	30	3:20								2	6	8	19	26	61	126:20
	40	3:10							1	6	11	16	19	49	84	190:20
270	5	4:10												1	3	8:30
	10	4:00											2	5	11	22:30
	15	3:50										3	4	11	24	46:30
	20	3:40									2	3	9	21	35	74:30

TABLE 1-14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet) 130	120	110	100	90	80	70	60	50	40	30	20	10	Total ascent time (min:sec)
270—Con.	25	3:30								2	3	8	13	23	53	106:30
	30	3:30								3	6	12	22	27	64	138:30
	40	3:20							5	6	11	17	22	51	88	204:30
280	5	4:20												2	2	8:40
	10	4:00										1	2	5	13	25:40
	15	3:50									1	3	4	11	26	49:40
	20	3:50									3	4	8	23	39	81:40
	25	3:40								2	5	7	16	23	56	113:40
	30	3:30							1	3	7	13	22	30	70	150:40
	40	3:20						1	6	6	13	17	27	51	93	218:40
290	5	4:30												2	3	9:50
	10	4:10										1	3	5	16	29:50
	15	4:00									1	3	6	12	26	52:50
	20	4:00									3	7	9	23	43	89:50
	25	3:50								3	5	8	17	23	60	120:50
	30	3:40							1	5	6	16	22	36	72	162:50
	40	3:30						3	5	7	15	16	32	51	95	228:50
300	5	4:40												3	3	11:00
	10	4:20										1	3	6	17	32:00
	15	4:10									2	3	6	15	26	57:00
	20	4:00								2	3	7	10	23	47	97:00
	25	3:50							1	3	6	8	19	26	61	129:00
	30	3:50							2	5	7	17	22	39	75	172:00
	40	3:40						4	6	9	15	17	34	51	90	231:00
	60	3:00		4	10	10	10	10	10	14	28	32	50	90	187	460:00

TABLE 1-14.—*U.S. Navy Standard Air Decompression Table for exceptional exposures*—Continued

Extreme exposures—250 and 300 ft

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Decompression stops (feet)																				Total ascent time (min:sec)
			200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	
250	120	1:50	----	----	----	----	----	----	5	10	10	10	10	16	24	24	36	48	64	94	142	187	684:10
	180	1:30	----	----	----	----	4	8	8	10	22	24	24	32	42	44	60	84	114	122	142	187	931:10
	240	1:30	----	----	----	----	9	14	21	22	22	40	40	42	56	76	98	100	114	122	142	187	1109:10
300	90	2:20	----	----	----	----	3	8	8	10	10	10	10	16	24	24	34	48	64	90	142	187	693:00
	120	2:00	----	----	4	8	8	8	8	10	14	24	24	24	34	42	58	66	102	122	142	187	800:00
	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

(FORMERLY TABLE 1-17, 1963 DIVING MANUAL)

TABLE 1-26.—*Surface decompression table using oxygen*

1	2	3	4				5	6	7	8
Depth (ft, gage)	Bottom time (min) [1]	Time to first stop or surface [2]	Time (min) breathing air at water stops (ft) [3]				Surface interval [4]	Time at 40-foot chamber stop (min) on oxygen [5]	Surface [6]	Total decompression time (min: sec) [7]
			60	50	40	30				
70	52	2:48	0	0	0	0	SURFACE INTERVAL NOT TO EXCEED 5 MINUTES	0	2-MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	2:48
	90	2:48	0	0	0	0		15		23:48
	[8] 120	2:48	0	0	0	0		23		31:48
	150	2:28	0	0	0	0		31		39:48
	180	2:48	0	0	0	0		39		47:48
80	40	3:12	0	0	0	0		0		3:12
	70	3:12	0	0	0	0		14		23:12
	85	3:12	0	0	0	0		20		29:12
	100	3:12	0	0	0	0		26		35:12
	[8] 115	3:12	0	0	0	0		31		40:12
	130	3:12	0	0	0	0		37		46:12
	150	3:12	0	0	0	0		44		53:12
90	32	3:36	0	0	0	0		0		3:36
	60	3:36	0	0	0	0		14		23:36
	70	3:36	0	0	0	0		20		29:36
	80	3:36	0	0	0	0		25		34:36
	[8] 90	3:36	0	0	0	0		30		39:36
	100	3:36	0	0	0	0		34		43:36
	110	3:36	0	0	0	0		39		48:36
	120	3:36	0	0	0	0		43		52:36
	130	3:36	0	0	0	0		48		57:36
100	26	4:00	0	0	0	0		0		4:00
	50	4:00	0	0	0	0		14		24:00
	60	4:00	0	0	0	0		20		30:00
	70	4:00	0	0	0	0		26		36:00
	[8] 80	4:00	0	0	0	0		32		42:00
	90	4:00	0	0	0	0		38		48:00
	100	4:00	0	0	0	0		44		54:00
	110	4:00	0	0	0	0		49		59:00
	120	4:00	0	0	0	0		53		63:00
110	22	4:24	0	0	0	0		0		4:24
	40	4:24	0	0	0	0		12		22:24
	50	4:24	0	0	0	0		19		29:24
	60	4:24	0	0	0	0		26		36:24
	[8] 70	4:24	0	0	0	0		33		43:24
	80	3:12	0	0	0	1		40		51:12
	90	3:12	0	0	0	2		46		58:12
	100	3:12	0	0	0	5		51		66:12
	110	3:12	0	0	0	12		54		76:12
120	18	4:48	0	0	0	0		0		4:48
	30	4:48	0	0	0	0		9		19:48
	40	4:48	0	0	0	0		16		26:48
	50	4:48	0	0	0	0		24		34:48
	[8] 60	3:36	0	0	0	2		32		44:36
	70	3:36	0	0	0	4		39		53:36
	80	3:36	0	0	0	5		46		61:36
	90	3:12	0	0	3	7		51		72:12
	100	3:12	0	0	6	15		54		86:12
130	15	5:12	0	0	0	0		0		5:12
	30	5:12	0	0	0	0		12		23:12
	40	5:12	0	0	0	0		21		32:12
	50	4:00	0	0	0	3		29		43:00
	[8] 60	4:00	0	0	0	5		37		53:00
	70	4:00	0	0	0	7		45		63:00
	80	3:36	0	0	6	7		51		75:36
	90	3:36	0	0	10	12		56		89:36

See footnotes at end of table.

TABLE 1-26.—*Surface decompression table using oxygen*—Continued

1	2	3	4				5	6	7	8
Depth (ft, gage)	Bottom time (min) [1]	Time to first stop or surface [2]	Time (min) breathing air at water stops (ft) [3]				Surface interval [4]	Time at 40-foot chamber stop (min) on oxygen [5]	Surface [6]	Total decompression time (min: sec) [7]
			60	50	40	30				
140	13	5:36	0	0	0	0	SURFACE INTERVAL NOT TO EXCEED 5 MINUTES	0	2-MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	5:36
	25	5:36	0	0	0	0		11		22:36
	30	5:36	0	0	0	0		15		26:36
	35	5:36	0	0	0	0		20		31:36
	40	4:24	0	0	0	2		24		37:24
	45	4:24	0	0	0	4		29		44:24
	50	4:24	0	0	0	6		33		50:24
	[8] 55	4:24	0	0	0	7		38		56:24
	60	4:24	0	0	0	8		43		62:24
	65	4:00	0	0	3	7		48		70:00
	70	3:36	0	2	7	7		51		79:36
150	11	6:00	0	0	0	0		0		6:00
	25	6:00	0	0	0	0		13		25:00
	30	6:00	0	0	0	0		18		30:00
	35	4:48	0	0	0	4		23		38:48
	40	4:24	0	0	3	6		27		48:24
	45	4:24	0	0	5	7		33		57:24
	[8] 50	4:00	0	2	5	8		38		66:00
	55	3:36	2	5	9	4		44		77:36
160	9	6:24	0	0	0	0		0		6:24
	20	6:24	0	0	0	0		11		23:24
	25	6:24	0	0	0	0		16		28:24
	30	5:12	0	0	0	2		21		35:12
	35	4:48	0	0	4	6		26		48:48
	40	4:24	0	3	5	8		32		61:24
	[8] 45	4:00	3	4	8	6		38		73:00
170	7	6:48	0	0	0	0		0		6:48
	20	6:48	0	0	0	0		13		25:48
	25	6:48	0	0	0	0		19		31:48
	30	5:12	0	0	3	5		23		44:12
	35	4:48	0	4	4	7		29		57:48
	[8] 40	4:24	4	4	8	6		36		72:24

[1] Time interval in minutes from leaving the surface to leaving the bottom.

[2] Time of ascent in minutes and seconds to the first stop or to the surface at a rate of 25 feet per minute.

[3] Water stops: Time spent at tabulated stops using air. If no water stops are required, use a 25-foot-per-minute rate of ascent to the surface. When water stops are required, use a 25-foot-per-minute rate of ascent to the first stop. Take an additional minute between stops. Use 1 minute for the ascent from 30 feet to the surface.

[4] Surface interval: The surface interval shall not exceed 5 minutes and is composed of the following elements:

a. Time of ascent from the 30-foot water stop to the surface (1 minute).

b. Time on the surface for landing the diver on deck and undressing (not to exceed 3 minutes and 30 seconds).

c. Time of descent in the recompression chamber from the surface to 40 feet (about 30 seconds).

[5] During the period of oxygen breathing, the chamber shall be ventilated unless an oxygen-elimination system is used

[6] Surfacing: Oxygen breathing during this 2-minute period shall follow without interruption the period of oxygen breathing tabulated in col. 6.

[7] Total decompression time in minutes and seconds. This time includes:

a. Time of ascent from the bottom to the first stop at 25 feet per minute, col. 3.

b. Sum of tabulated water stops, col. 4.

c. One minute between water stops.

d. The surface interval, col. 5.

e. Time at 40 feet in the recompression chamber, col. 6.

f. Time of ascent, an additional 2 minutes, from 40 feet to the surface, col. 7.

The total decompression time may be shortened only by decreasing the time required to undress the diver on deck.

[8] These are the optimum exposure times for each depth and represent for the average diver the best balance of safety, length of work period, and amount of useful work. Exposure beyond these limits of time is permitted only under special conditions.

(FORMERLY TABLE 1-18, 1963 DIVING MANUAL)

TABLE 1-27.—*Surface decompression table using air*

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min)				Chamber stops (air) (min)		Total ascent time (min:sec)
			30	20	10		20	10	
40	230	0:30			3	TIME ON SURFACE NOT TO EXCEED 3 MINUTES AND 30 SECONDS		7	14:30
	250	:30			3			[illegible]	18:30
	270	:30			3			15	22:30
	300	:30			3			19	26:30
50	120	:40			3			5	12:40
	140	:40			3			10	17:40
	160	:40			3			21	28:40
	180	:40			3			29	36:40
	200	:40			3			35	42:40
	220	:40			3			40	47:40
	240	:40			3			47	54:40
60	80	:50			3			7	14:50
	100	:50			3			14	21:50
	120	:50			3			26	33:50
	140	:50			3			39	46:50
	160	:50			3			48	55:50
	180	:50			3			56	63:50
	200	:40		3			3	69	80:10
70	60	1:00			3			8	16:00
	70	1:00			3			14	22:00
	80	1:00			3			18	26:00
	90	1:00			3			23	31:00
	100	1:00			3			33	41:00
	110	:50		3			3	41	52:20
	120	:50		3			4	47	59:20
	130	:50		3			6	52	66:20
	140	:50		3			8	56	72:20
	150	:50		3			9	61	78:20
	160	:50		3			13	72	93:20
	170	:50		3			19	79	106:20
80	50	1:10			3			10	18:10
	60	1:10			3			17	25:10
	70	1:10			3			23	31:10
	80	1:00		3			3	31	42:30
	90	1:00		3			7	39	54:30
	100	1:00		3			11	46	65:30
	110	1:00		3			13	53	74:30
	120	1:00		3			17	56	81:30
	130	1:00		3			19	63	90:30
	140	1:00		26			26	69	126:30
	150	1:00		32			32	77	146:30
90	40	1:20			3			7	15:20
	50	1:20			3			18	26:20
	60	1:20			3			25	33:20
	70	1:10		3			7	30	45:40
	80	1:10		13			13	40	71:40
	90	1:10		18			18	48	89:40
	100	1:10		21			21	54	101:40
	110	1:10		24			24	61	114:40
	120	1:10		32			32	68	137:40
	130	1:00	5	36			36	74	156:40

TABLE 1-27.—*Surface decompression table using air*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min)					TIME ON SURFACE NOT TO EXCEED 3 MINUTES AND 30 SECONDS	Chamber stops (air) (min)		Total ascent time (min:sec)
			50	40	30	20	10		20	10	
100	40	1:30					3			15	23:30
	50	1:20				3			3	24	35:50
	60	1:20				3			9	28	45:50
	70	1:20				3			17	39	64:50
	80	1:20				23			23	48	99:50
	90	1:10			3	23			23	57	111:50
	100	1:10			7	23			23	66	124:50
	110	1:10			10	34			34	72	155:50
	120	1:10			12	41			41	78	177:50
	30	1:40					3			7	15:40
	40	1:30				3			3	21	33:00
	50	1:30				3			8	26	43:00
	60	1:30				18			18	36	78:00
	70	1:20			1	23			23	48	101:00
	80	1:20			7	23			23	57	116:00
110	90	1:20			12	30			30	64	142:00
	100	1:20			15	37			37	72	167:00
120	25	1:50					3			6	14:50
	30	1:50					3			14	22:50
	40	1:40				3			5	25	39:10
	50	1:40				15			15	31	67:10
	60	1:30			2	22			22	45	97:10
	70	1:30			9	23			23	55	116:10
	80	1:30			15	27			27	63	138:10
	90	1:30			19	37			37	74	173:10
	100	1:30			23	45			45	80	189:10
130	25	2:00					3			10	19:00
	30	1:50				3			3	18	30:20
	40	1:50				10			10	25	51:20
	50	1:40			3	21			21	37	88:20
	60	1:40			9	23			23	52	113:20
	70	1:40			16	24			24	61	131:20
	80	1:30		3	19	35			35	72	170:20
	90	1:30		8	19	45			45	80	203:20
140	20	2:10					3			6	15:10
	25	2:00				3			3	14	26:30
	30	2:00				5			5	21	37:30
	40	1:50			2	16			16	26	66:30
	50	1:50			6	24			24	44	104:30
	60	1:50			16	23			23	56	124:30
	70	1:40		4	19	32			32	68	161:30
	80	1:40		10	23	41			41	79	200:30
150	20	2:10				3			3	7	19:40
	25	2:10				4			4	17	31:40
	30	2:10				8			8	24	46:40
	40	2:00			5	19			19	33	82:40
	50	2:00			12	23			23	51	115:40
	60	1:50		3	19	26			26	62	142:40
	70	1:50		11	19	39			39	75	189:40
	80	1:40	1	17	19	50			50	84	227:40
160	20	2:20				3			3	11	23:50
	25	2:20				7			7	20	40:50
	30	2:10			2	11			11	25	55:50
	40	2:10			7	23			23	39	98:50
	50	2:00		2	16	23			23	55	125:50
	60	2:00		9	19	33			33	69	169:50
	70	1:50	1	17	22	44			44	80	214:50
170	15	2:30				3			3	5	18:00
	20	2:30				4			4	15	30:00
	25	2:20			2	7			7	23	46:00
	30	2:20			4	13			13	26	63:00
	40	2:10		1	10	23			23	45	109:00
	50	2:10		5	18	23			23	61	137:00
	60	2:00	2	15	22	37			37	74	194:00
	70	2:00	8	17	19	51			51	86	239:00

TABLE 1-27.—*Surface decompression table using air*—Continued

Depth (ft)	Bottom time (min)	Time to first stop (min:sec)	Time at water stops (min)					TIME ON SURFACE NOT TO EXCEED 3 MINUTES AND 30 SECONDS	Chamber stops (air) (min)		Total ascent time (min:sec)
			50	40	30	20	10		20	10	
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	164:20
	60	2:20	10	17	19	50			50	84	237:20

NOTE.—The ascent rates in this table are 60 feet per minute to the first stop, between stops and to the surface in the water and in the chamber. The descent rate in the chamber is also 60 feet per minute. The total ascent time may be shortened only by shortening the surface-interval.

(FORMERLY TABLE 1-20, 1963 DIVING MANUAL)

TABLE 1-29.—*Treatment of an unconscious diver*

(Loss of consciousness during, or within 24 hours after, a dive. See 1.6.4)

1. If the diver is not breathing, start mouth-to-mouth or manual artificial respiration at once (see app. A).
2. Recompress promptly (see note *d*).
3. Examine for injuries and other abnormalities; apply first aid and other measures as required. (Secure the help of a medical officer as soon as possible.)

Notes

Artificial respiration:

a. Shift to a mechanical resuscitator if one is available and working properly, but never wait for it. Always start the mouth-to-mouth or manual methods first.

b. Continue artificial respiration by some method without interruption until normal breathing resumes or the victim is pronounced dead. Continue on the way to the chamber and during recompression. (Do not use oxygen deeper than 60 feet in the chamber.)

Recompression:

c. Remember that an unconscious diver may have air embolism or serious decompression sickness even though some other accident seems to explain his condition.

d. Recompress unless—

1. The victim regains consciousness and is free of nervous system symptoms before recompression can be started.
2. The possibility of air embolism or decompression sickness can be ruled out without question.
3. Another lifesaving measure is absolutely required and makes recompression impossible.

e. Try to reach a recompression chamber no matter how far it is.

f. Treat according to the treatment tables (see tables 1-30 and 1-31), depending on response. Remember that early recovery under pressure never rules out the need for adequate treatment.

(FORMERLY TABLE 1-21, 1963 DIVING MANUAL)

TABLE 1-30.—*Treatment of decompression sickness and air embolism*

Stops		Bends—pain only				Serious symptoms	
Rate of descent—25 feet per minute. Rate of ascent—1 minute between stops.		Pain relieved at depths less than 66 feet. Use table 1A if O_2 is not available.		Pain relieved at depths greater than 66 feet. Use table 2A if O_2 is not available. If pain does not improve within 30 minutes at 165 feet, the case is probably not bends. Decompress on table 2 or 2A.		Serious symptoms include any one of the following: 1. Unconsciousness. 2. Convulsions. 3. Weakness or inability to use arms or legs. 4. Air embolism. 5. Any visual disturbances. 6. Dizziness. 7. Loss of speech or hearing. 8. Severe shortness of breath or chokes. 9. Bends occurring while still under pressure.	
						Symptoms relieved within 30 minutes at 165 feet. Use table 3	Symptoms not relieved within 30 minutes at 165 feet. Use table 4
Pounds	**Feet**	**Table 1**	**Table 1A**	**Table 2**	**Table 2A**	**Table 3**	**Table 4**
73.4	165	....	....	30 (air)	30 (air)	30 (air)	30 to 120 (air)
62.3	140	....	....	12 (air)	12 (air)	12 (air)	30 (air)
53.4	120	....	....	12 (air)	12 (air)	12 (air)	30 (air)
44.5	100	30 (air)	30 (air)	12 (air)	12 (air)	12 (air)	30 (air)
35.6	80	12 (air)	12 (air)	12 (air)	12 (air)	12 (air)	30 (air)
26.7	60	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
22.3	50	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
17.8	40	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hr (air)
13.4	30		60 (air)	60 (O_2)	2 hr (air)	12 hr (air)	First 11 hr (air) Then 1 hr (O_2) or (air)
8.9	20	5 (O_2)	60 (air)		2 hr (air)	2 hr (air)	First 1 hr (air) Then 1 hr (O_2) or (air)
4.5	10		2 hr (air)	5 (O_2)	4 hr (air)	2 hr (air)	First 1 hr (air) Then 1 hr (O_2) or (air)
Surface			1 min (air)		1 min (air)	1 min (air)	1 min (O_2)

Time at all stops in minutes unless otherwise indicated.

TABLE 1-31.—*Minimal recompression, oxygen breathing method for treatment of decompression sickness and air embolism*

Stops	Bends—pain only			Serious symptoms and air embolism								
(a)	Pain relieved within 10 minutes at 60 feet. If any pain persists after 10 minutes at 60 feet, use table 6.			Pain relieved after 10 minutes at 60 feet. Serious symptoms include any one of the following: 1. Unconsciousness. 2. Nervous system symptoms. 3. Bends under pressure.			Treatment of air embolism. Rate of descent is as fast as possible. Use this table if all symptoms are gone within 15 minutes and proceed to 60 feet when relief is complete.			Treatment of air embolism if symptoms moderate to a major extent within 30 minutes at 60 feet. If symptoms persist, use table 4.		
	Table 5 [b]			Table 6 [b]			Table 5A [c]			Table 6A [c]		
Depth (feet)	Time (minutes)	Breathing media	Total elapsed time (minutes)	Time (minutes)	Breathing media	Total elapsed time (minutes)	Time (minutes)	Breathing media	Total elapsed time (minutes)	Time (minutes)	Breathing media	Total elapsed time (minutes)
165							[d] 15	Air	15	30	Air	30
165 to 60							4	Air	19	4	Air	34
60				20	Oxygen	20				20	Oxygen	54
60				5	Air	25				5	Air	59
60				20	Oxygen	45				20	Oxygen	79
60	20	Oxgyen	20	5	Air	50	20	Oxygen	39	5	Air	84
60	5	Air	25	20	Oxygen	70	5	Air	44	20	Oxygen	104
60	20	Oxygen	45	5	Air	75	20	Oxygen	64	5	Air	109
60 to 30	30	Oxygen	75	30	Oxygen	105	30	Oxygen	94	30	Oxygen	139
30				15	Air	120				15	Air	154
30	5	Air	80	60	Oxygen	180	5	Air	99	60	Oxygen	214
30	20	Oxygen	100	15	Air	195	20	Oxygen	119	15	Air	229
30	5	Air	105	60	Oxygen	255	5	Air	124	60	Oxygen	289
30 to 0	30	Oxygen	135	30	Oxygen	285	30	Oxygen	154	30	Oxygen	319

[a] The rate of ascent is 1 foot per minute. Do not compensate for slowing of the rate by subsequent acceleration. Do compensate if the rate is exceeded. If necessary, halt ascent and hold depth while ventilating the chamber.

[b] The time at 60 feet begins on arrival at 60 feet. The patient should be on oxgyen from the surface.

[c] The time at 165 feet is total bottom time and includes the time from the surface.

[d] Total time will vary as a function of this stop. The medical attendant should take enough time to accomplish a thorough physical examination, because the ensuing treatment is based on the patient's physical status.

(FORMERLY TABLE 1-22, 1963 DIVING MANUAL)

TABLE 1-32.—*Notes on recompression*

1. General considerations:
    a. Follow the treatment tables (table 1-30 or 1-31) accurately.
    b. Permit no shortening or other alterations of the tables except on the advice of a trained diving medical officer or in an extreme emergency.
2. Rate of descent in the chamber:
    a. The normal descent rate is 25 feet per minute.
    b. If serious symptoms are present: rapid descent is desirable.
    c. If pain increases on descent: stop, resume at a rate tolerated by the patient.
3. Treatment depth:
    a. Go to the full depth indicated by the table required.
    b. Do not go beyond 165 feet except on the decision of a medical officer who has been trained in diving.
4. Examination of the patient (see 1.6.2):
    a. If no serious symptoms are evident and pain is not severe, examine the patient thoroughly before treatment.
    b. If any serious symptom is noted, do not delay recompression for examination or for determining depth of relief.
    c. If Treatment Tables 5, 6, 5A, or 6A are used, a medical officer must be present and a qualified medical attendant must always accompany the patient in the chamber during treatment.
    d. In "pain only" cases, make sure that relief is complete within 10 minutes at 60 feet on oxygen if table 5 is used. If not, table 6 may be used. If table 1 is used, make sure that complete relief has been reported before reaching 66 feet.
    e. On reaching treatment depth, examine the patient as completely as possible to detect
        1. Incomplete relief.
        2. Any symptoms overlooked.

NOTE

At the very least, have the patient stand and walk the length of the chamber if this is at all possible.

    f. Recheck the patient before leaving the treatment depth.
    g. Ask the patient how he feels before and after coming to each stop and periodically during long stops.
    h. Do not let the patient sleep through changes of depth or for more than an hour at a time at any stop. (Symptoms can develop or recur during sleep.)
    i. Recheck the patient before leaving the last stop.
    j. During treatment make sure that the patient can obtain all the things that he needs, such as food, liquids, and any other items that he might require.
5. Patient getting worse:
    a. Never continue ascent if the patient's condition is worsening.
    b. Treat the patient as a recurrence during treatment (see 6).
    c. Consider the use of helium-oxygen as a breathing medium for the patient (see 8).
6. Recurrence of symptoms:
    a. During treatment:
        1. Recompress to depth of relief (but never less than 30 feet or deeper than 165 feet except on decision of a medical officer).
        2. If a medical officer is available and the depth of relief is less than 60 feet, recompress to 60 feet and treat on table 6.
        3. If a medical officer is not available or the depth of relief is greater than 60 feet, complete the treatment according to table 4; i.e., remain at depth of relief for 30 minutes and complete remaining stops of table 4.
        4. If recurrence involves serious symptoms not previously present, take the patient to 60 feet and treat on table 6 or take the patient to 165 feet and treat on table 4.
    b. Following treatment:
        1. Recompress to 60 feet and use table 6 if a medical officer is available.
        2. If the depth of relief is less than 30-feet, recompress the patient to 30 feet and decompress from the 30-foot stop according to table 3.
        3. If the depth of relief is deeper than 30 feet, keep the patient at depth of relief for 30 minutes and decompress according to table 3.

TABLE 1-32.—*Notes on recompression*—Continued

6. Recurrence of symptoms—Continued
   - *b.* Following treatment—Continued
     - *4.* If the original treatment was on table 5 or 6, use table 6. If the original treatment was on table 5A or 6A, use table 6, 6A, or table 4. If the original treatment was on table 3, use table 6, 6A, or table 4.
     - *5.* Examine the patient carefully to be sure no serious symptom is present. If the original treatment was on table 1 or 2, appearance of a serious symptom requires full treatment on table 6, 3, or 4.
   - *c.* Using oxygen treatment tables during or following treatment:
     - *1.* Table 6 can be lengthened by an additional 25 minutes at 60 feet (20 minutes on oxygen and 5 minutes on air) or an additional 75 minutes at 30 feet (15 minutes on air and 60 minutes on oxygen), or both. Table 6A can be lengthened in the same manner.
     - *2.* If relief is not complete at 60 feet or if the patient's condition is worsening, the additional time above may be used or the patient can be recompressed to 165 feet and treated on table 2, 2A, 3, or 4 as appropriate.

7. Use of oxygen:
   - *a.* Use oxygen wherever permitted by the treatment tables unless the patient is known to tolerate oxygen poorly.
   - *b.* If a medical officer trained in diving is available, he may recommend the use of oxygen for patients who are known to tolerate oxygen poorly.
   - *c.* Take all precautions against fire (see table 1-34).
   - *d.* Tend carefully, being alert for such symptoms of oxygen poisoning as—
     - *1.* Twitching of the face and lips.
     - *2.* Nausea.
     - *3.* Dizziness and vertigo.
     - *4.* Vomiting.
     - *5.* Convulsions.
     - *6.* Anxiety.
     - *7.* Confusion.
     - *8.* Restlessness and irritability.
     - *9.* Malaise or excessive tiredness.
     - *10.* Changes in vision as blurring or narrowing of the visual field.
     - *11.* Incoordination.
     - *12.* Tremors of the arms and legs.
     - *13.* Numbness or tingling of the fingers or toes.
     - *14.* Fainting.
     - *15.* Spasmodic breathing.
   - *e.* Know what to do in the event of a convulsion:
     - *1.* Halt ascent.
     - *2.* Remove mask at once.
     - *3.* Maintain depth.
     - *4.* Protect the convulsing patient from injury but do not restrain or forcefully oppose the convulsive movements.
     - *5.* Use a padded mouth bit to protect the tongue of a convulsing patient.
     - *6.* If the patient is not convulsing, have him hyperventilate with chamber air for a few breaths.
   - *f.* If oxygen breathing must be interrupted:
     - *1.* On table 1, proceed on table 1A.
     - *2.* On table 2, proceed on table 2A.
     - *3.* On table 3, continue on table 3, using air.
     - *4.* On table 5, 6, 5A, or 6A, allow 15 minutes after the reaction has entirely subsided and resume the schedule at the point of its interruption.
     - *5.* On table 5, if the reaction occurred at 60 feet, upon arrival at the 30-foot stop, switch to the schedule of table 6.
   - *g.* At the medical officer's discretion, oxygen breathing may be resumed at the 40-foot stop. If oxygen breathing is resumed, complete treatment as follows:
     - *1.* Resuming from table 1A: breathe oxygen at 40 feet for 30 minutes and at 30 feet for 1 hour.
     - *2.* Resuming from table 2A: breathe oxygen at 40 feet for 30 minutes and at 30 feet for 2 hours.
     - *3.* In both cases, then surface in 5 minutes, still breathing oxygen.
     - *4.* Resuming from table 3: breathe oxygen at 40 feet for 30 minutes and at 30 feet for the first hour, and then finish the treatment with air.

TABLE 1-32.—*Notes on recompression*—Continued

8. Use of helium-oxygen:
   - *a.* Helium-oxygen mixtures in a ratio of about 80:20 can be used instead of air (not in place of oxygen) in all types of treatment and at any depth.
   - *b.* The use of helium-oxygen mixtures is especially desirable in any patient who—
     - *1.* Has serious symptoms which fail to clear within a short time at 165 feet.
     - *2.* Has a recurrence of symptoms or otherwise becomes worse at any stage of treatment.
     - *3.* Has any difficulty in breathing.
9. Tenders:
   - *a.* A qualified tender must be in the chamber at all times.
   - *b.* The tender must be alert for any change in the condition of the patient, especially during oxygen breathing.
   - *c.* The tender must breathe oxygen if he has been with a patient throughout treatment using table 1 or 2.
     - *1.* On table 1, breathe oxygen at 40 feet for 30 minutes.
     - *2.* On table 2, breathe oxygen at 30 feet for 1 hour.
   - *d.* A tender in the chamber only during the oxygen-breathing part of table 1 or 2 gains a safety factor by breathing oxygen for 30 minutes of the last stop, but it is not essential. Tenders may breathe oxygen during the use of table 3 or 4 at depths of 40 feet or less.
   - *e.* When tables 5, 6, 5A, and 6A are used, the tender normally breathes air throughout. However, if the treatment is a repetitive dive for the tender or if tables 6 or 6A are lengthened, the tender must breathe oxygen during the last 30 minutes of ascent from 30 feet to the surface.
   - *f.* Anyone entering the chamber and leaving before completion of the treatment must be decompressed according to standard diving tables.
   - *g.* Personnel outside the chamber must specify and control the decompression of anyone leaving the chamber and must review all decisions concerning treatment or decompression made by personnel (including the medical officer) inside the chamber.
10. Ventilation of the chamber:
   - *a.* All ventilation will be continuous and the volumes specified are measured at the chamber pressure.
   - *b.* If ventilation must be interrupted for any reason, the time will not exceed 5 minutes in any 30-minute period. When the ventilation is resumed, twice the volume of ventilation will be used for twice the time of the interruption and then the basic ventilation will be used again.
   - *c.* When air or a helium-oxygen mixture is breathed, provide 2 cubic feet per minute for a man at rest and 4 cubic feet per minute for a man who is not at rest, such as a tender actively taking care of a patient.
   - *d.* When oxygen is breathed, provide 12.5 cubic feet per minute for a man at rest and 25 cubic feet per minute for a man who is not at rest. When these ventilation rates are used, no additional ventilation is required for personnel breathing air. These ventilation rates apply only to the number of people breathing oxygen.
   - *e.* The above rules apply to all chambers that do not have facilities to monitor the oxygen concentration in the chamber. Chambers that can monitor oxygen concentration may use intermittent ventilation so that the oxygen concentration in the chamber does not exceed 22.5 percent. This ventilation also requires no additional ventilation for personnel breathing air.
   - *f.* If an oxygen-elimination system is used for oxygen breathing (see app. B) the ventilation rate required for air breathing may be used and applies to all personnel, whether or not the oxygen-elimination system is used to obtain the correct ventilation rate.
11. First aid:
   - *a.* First aid may be required in addition to recompression. Do not neglect it (see table 1-33 and app. A).
12. Recompression in the water:
   - *a.* Recompression without a chamber is difficult and hazardous. Except in grave emergencies, seek the nearest chamber even if it is at a considerable distance.
   - *b.* If water recompression must be used and the diver is conscious and able to care for himself:
     - *1.* Use the deep-sea diving rig if available.
     - *2.* Follow treatment tables as closely as possible.
     - *3.* Maintain constant communication.
     - *4.* Have a standby diver ready and preferably use a tender with the patient.
   - *c.* If the diver is unconscious or incapacitated, send another diver down with him to control his valves and otherwise assist him.
   - *d.* If lightweight diving outfit or scuba must be used, keep at least one diver with the patient at all times. Plan carefully for shifting rigs or cylinders. Have an ample number of tenders topside and at intermediate depths.

TABLE 1-32.—*Notes on recompression*—Continued

12. Recompression in the water—Continued
    - *e.* If depth is inadequate for full treatment according to the tables:
        - *1.* Take the patient to maximum available depth.
        - *2.* Keep him there for 30 minutes.
        - *3.* Bring him up according to table 2A. Do not use stops shorter than those of table 2A.
13. The most frequent errors related to treatment:
    - *a.* Failure of the diver to report symptoms early.
    - *b.* Failure to treat doubtful cases.
    - *c.* Failure to treat promptly.
    - *d.* Failure to treat adequately.
    - *e.* Failure to recognize serious symptoms.
    - *f.* Failure to keep the patient near the chamber after treatment.
14. ALWAYS KEEP THE DIVER CLOSE TO THE CHAMBER FOR AT LEAST 6 HOURS AFTER TREATMENT. (Keep him for 24 hours unless very prompt return can be assured.)

TABLE 1-33.—*Notes on artificial respiration*

1. Start artificial respiration immediately whenever a man is *not breathing* due to drowning or any other cause.
    - *a.* Never wait for mechanical resuscitator.
    - *b.* Delay *only* to stop serious bleeding (if possible have another person tend to such measures while you start artificial respiration).
    - *c.* Send *another person* for a medical officer or other competent aid.
2. Before starting, remove victim from the cause of his trouble; but do not waste time moving him any further than necessary.
3. *Get on with artificial respiration.* Leave details to others or try to get them done quickly between cycles.
    - *a.* Recheck position of victim:
        - *1.* In position for mouth-to-mouth resuscitation.
        - *2.* Head slightly lower than feet if possible, especially in drowning.
        - *3.* Chin pulled toward operator.
    - *b.* Recheck airway:
        - *1.* Remove froth, debris, or other material.
        - *2.* See that tongue stays forward; have someone hold it if it draws back (you can run a safety pin through tongue if necessary).
        - *3.* If *artificial respiration does not move any air, there is an obstruction.* Strangulation must be overcome (see app. A).
    - *c.* Loosen any tight clothing—collar, belt, etc.
    - *d.* Keep victim warm.
    - *e.* Check pulse. Combat shock.
4. Continue artificial respiration without interruption. (Minimum time is 4 hours unless victim revives or is pronounced dead by medical officer.)
    - *a.* Do not apply *too much* back pressure. (A strong operator can crack ribs of a small victim.)
    - *b.* If you become tired, let another operator take over. Do not break rhythm during shift.
    - *c.* Watch carefully for signs of return of natural breathing movements. If they appear, time your movements to assist them.
    - *d.* Shift to a mechanical resuscitator if one is available, ready, and operating properly.
    - *e.* If victim starts breathing for himself, watch him carefully. Resume artificial respiration if he stops or if movements become too feeble.
5. If victim revives, continue care:
    - *a.* Keep him lying down.
    - *b.* Remove wet clothes; keep him warm.
    - *c.* Give nothing by mouth until fully conscious.
    - *d.* Attend to any injuries.
    - *e.* Be sure he is seen promptly by medical officer.

NOTE

If victim has been underwater with any kind of breathing apparatus, he *may have air embolism.* This can seldom be ruled out in an unconscious diver, whether he is breathing or not, and recompression should be given if any doubt exists. Do not delay artificial respiration. Give it by some method on way to chamber and during recompression.

TABLE 1-34.—*Precautions in use of recompression chamber*

Preparedness

The personnel and facilities of every Navy diving activity must be ready to treat decompression sickness or air embolism at a moment's notice at any time.

1. The chamber and its auxiliary equipment must be in working order and ready for use. Follow routine of periodic tests and preventive maintenance. Check the following:
   a. The chamber itself—free of extraneous gear, equipped and ready.
   b. The air supply—banks charged, compressor ready to operate.
   c. Communication gear—functioning properly.
   d. Oxygen installation—cylinders full, demand valves operative.
   e. Medical kit—stocked and at hand.
2. Personnel must be trained in operation of equipment and be able to do any job required in treatment; definite assignment of responsibilities is required.
   a. Hold periodic training runs with rotation of personnel.
   b. Provide emergency bill, listing jobs and duties.

General Precautions in Use

1. Avoid damage to doors and dogs. Use minimum force required in "dogging down"; be sure dogs are released before pressure is reduced.
2. Provide ample chamber ventilation, especially when oxygen is being used.
3. Assure accurate timekeeping and recording.
4. Keep tender with patient especially when breathing oxygen.
5. Assure proper decompression of all persons entering chamber.

Prevention of Fire

1. Remove all combustible materials and replace with metal or fireproof construction (deck gratings, benches, etc.).
2. Use only fire-retarding paint; keep painting to minimum.
3. Keep chamber clean and free from all oily deposits and volatile materials of any kind. Keep all air filters clean.
4. Ventilate thoroughly after painting or unavoidable presence of any flammable substances.
5. Use no oil on any oxygen fitting or equipment.
6. Keep bedding and clothing to minimum. Be sure mattress, if used, is covered with fire-resistant material. Use flameproof bedding material. Be sure that clothing is free of grease and oil.
7. Locate all electrical switches outside chamber. Keep electrical system in perfect condition. Prohibit use of any electrical appliance in chamber during oxygen breathing.
8. Let no flame, matches, cigarette lighter, lighted cigarette, cigar, or pipe be carried into the chamber at any time.
9. Assure ample ventilation of chamber during use of oxygen and before any appliance is used.
10. Provide water and sand buckets.
11. Display the following warning prominently inside and outside the chamber:

WARNING

Danger of fire and explosion is much greater in an oxygen or a compressed-air atmosphere than in normal atmosphere at sea-level pressures. Do not admit flames, sparks, volatile or flammable substances, or unnecessary combustibles of any kind. Provide ample ventilation during oxygen breathing. Electrical appliances should not be used during oxygen-breathing periods or when the chamber atmosphere is compressed air.

APPENDIX D

EMERGENCY PROCEDURES FOR DIVING ACCIDENTS IN MICHIGAN AREA

EMERGENCY PROCEDURES FOR DIVING ACCIDENTS IN THE MICHIGAN AREA

It is essential that all persons engaging in underwater operations activities be well informed as to the location of recompression facilities for emergency treatment of air embolism and decompression sickness. Casualties must be transported to a recompression facility as quickly as possible. Divers and diving instructors are encouraged to formulate emergency transportation plans for use in their local area. For additional details on transportation and care of diving accident victims, refer to Kindwall et al. (1971).

In general the most rapid means of transportation is desirable, providing that it is reasonably safe and practical. If distances are relatively short, the best method of travel for the victim is by ambulance. However, if the distance to be traveled is great, helicopter transportation is recommended. Helicopter emergency service may be requested by proper authorities (doctor, state police, sheriff, etc.) from National Guard camps, US Air Force bases, US Coast Guard, US Naval Air Stations, and civilian airports. Phone numbers for the nearest facility can be obtained from the telephone operator. Transportation by regular airplane may further aggravate the victim's condition; however, if regular airplane transportation is the only feasible method, the plane should fly as close to the ground as practical and safe.

Information on ambulance services (ground and air) for southeastern Michigan can be obtained from Superior Ambulance Service, phone 800-552-4930. Local state police posts and sheriff's departments will be helpful in formulating emergency plans.

Operational recompression chambers known to exist in the Great Lakes area at present are listed below (operational status and telephone numbers should be verified before conducting extensive operations in a given area):

MICHIGAN

At the time of printing (August 1972) these chambers were verified as operational with capability of providing adequate treatment for diving accidents.

William Baumont Hospital
3601 W. 13 Mile Road
Royal Oak
Phone: (313) 549-7000

Small one-man chamber--use only as a last resort

The University of Michigan
Underwater Operations Laboratory
1038 G.G. Brown Building
Ann Arbor,
Phone: (313) 764-9522 or
764-9530 or 761-7928
Dr. Martin Nemiroff

Since this is a mobile unit, the chamber location and availability must be verified with the Michigan State Police Operations Center in Lansing.

WISCONSIN

St. Lukes Hospital
2900 W. Oklahoma Ave.
Milwaukee,
Phone: (414) 647-6423
Dr. Eric Kindwall

Milwaukee County Hospital
2400 W. Wisconsin Ave.
Chamber at 2430 W. Wisconsin Ave.
Milwaukee,
Phone: (414) 342-3065 or 774-3232

ILLINOIS

Lutheran General Hospital
1775 Dempster Ave.
Park Ridge,
Phone: (312) 692-2210,
ext. 1365

St. James Hospital
Chicago Road at 14th Street
Chicago Heights,
Phone: (312) 765-1000

Cook County Hospital
1825 West Harrison St.
Chicago,
Phone: (312) 633-6570

Edgewater Hospital
Hyperbaric Unit
5700 N. Ashland Avenue
Chicago,
Phone: (312) 878-6000, ext. 180 or 184

OHIO

Battelle Columbus Labs.
Battelle Memorial Inst.
505 King Ave.
Columbus,
Phone: (614) 299-3151,
ext. 2683

Ohio State Univ., College of Medicine
Wiseman Hall
400 West 12th Ave.
Columbus,
Phone: (614) 422-8736

Wright Patterson Air Force
Base
Dayton,
Phone: (513) 255-5713

Maumee Valley Hospital
2025 Arlington Road
Toledo,
Phone: (419) 385-4661, ext. 245

MINNESOTA

Minneapolis Medical Res. Foundation
Hennepin County Hospital
619 S. Fifth St.
Minneapolis,
Phone: (612) 330-2276, 330-2370
330-2522, 330-3965

NEW YORK

Millard Fillmore Hospital
Hyperbaric Unit
3 Gates Circle
Buffalo,
Phone: (716) 882-8000

Department of Physiology
School of Medicine
State University at Buffalo
Sherman Hall, The Circle
Buffalo,
Phone: (716) 831-2746

Veterans Administration Hospital
3495 Bailey Avenue
Buffalo,
Phone: (716) 892-9200, ext. 261 or 395

CANADA

Toronto General Hospital
Toronto,
Phone: (416) 366-8211

Royal Vicoria Hospital
867 Pine St.
Montreal,
Phone: (515) 842-1251

Defense Research Est. (Toronto)
1130 Sheppard West
Downsview,
Phone: (416) 633-4240

For further information on chambers and their operational status, consult US Navy (1971) and Kindwall et al. (1971). Since situations change rapidly at medical treatment facilities and data verification is difficult, neither I, the University of Michigan Sea Grant Program, nor above-mentioned authors can assume responsibility for the accuracy of this data at any given time.

The hospital authorities must be alerted and clearance obtained before making the trip. Ground transportation or assistance may be obtained from state police or sheriff offices. For military helicopter service, proper authorities may contact the commanding officer of any of the following airfields closest to the sphere of operations:

Selfridge Air Forge Base
Mt. Clemens, Michigan
Phone: (313) 465-1241

Wurtsmith Air Force Base
Oscoda, Michigan
Phone: (517) 739-3611

Kincheloe Air Force Base
Kinross, Michigan
Phone: (906) 495-5611

Naval Air Station
Grosse Ile, Michigan
Phone: (313) 676-3600

Coast Guard Air Station
Traverse City, Michigan
Phone: (616) 946-4650

Coast Guard Air Ambulance
Phone: (216) 522-3983

Any physician may obtain consultation with physicians who are acquainted with diagnosis and treatment of conditions requiring recompression from the hospitals.

The US Navy Experimental Diving Unit and Deep-Sea Diving School, Washington Navy Yard, Washington, D.C., maintain a listing of recompression chambers and physicians qualified in submarine medicine. The location of the nearest chambers and qualified medical personnel may be obtained by telephone from this organization. Any physician may also obtain consultation with US Navy medical personnel. A 24-hr watch is maintained. The 24-hr emergency number at the Experimental Diving Unit is (202) 433-2790. Other EDU numbers are 433-3717 and 433-3718. US Navy facilities in Washington, D.C., can be reached through the US Naval Station operator, phone: (202) 433-6700.

PROCEDURES FOR MICHIGAN AREA DIVERS:

1. Contact the nearest state police post. The state police will contact their operations center for details.

2. Advise the state police of the accident and the exact location.

3. Request a physician and ambulance.

4. Indicate that the victim will probably need recompression. Request that the state police contact the nearest chamber and arrange for transportation to the chamber. US Coast Guard helicopters may be necessary.

NOTE: The physician will have to make the final decision on treatment and recompression. You, as a first-aider, can only advise and give all details needed as clearly and accurately as possible. Be sure that all concerned know that it was a SCUBA diving accident.

5. Send a member of the diving team with the physician and victim to advise the chamber physician of the exact conditions of the accident.

References

Kindwall, E.; Schench, H.; and McAniff, J., "Nonfatal, Pressure-Related SCUBA Accidents, Identification and Emergency Treatment, SCUBA Safety Report 3 (Kingston, R.I.: Department of Ocean Engineering, University of Rhode Island, 1971).

US Navy, "Directory of World-Wide, Shore-Based Hyperbaric Chambers, Vol. 1: United States and Canada," NAVSHIPS 0994-010-4011 (Washington, D.C.: Supervisor of Salvage, Department of the Navy, 1971).

APPENDIX E

CONVERSION FACTORS

(FROM US NAVY DIVING MANUAL, 1970)*

*US Navy, "US Navy Diving Manual," NAVSHIPS 0994-001-9010 (Washington, D.C.: US Government Printing Office, 1970).

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

Length

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

Area

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

Volume (cubic measurements)

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

Capacity (liquid measure)

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

Weight (avoirdupois)

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

Weights of water

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

Pressure

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

[U.S. units to metric units]

Length

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

Area

1 sq in = 6.45 cm^2
1 sq ft = 929.03 cm^2
= 0.0929 m^2

Volume and capacity

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

Weight

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

Pressure

1 psi = 70.3 gm/cm^2
= 0.0703 kg/cm^2
= 0.703 m of fresh water
= 5.17 cm Hg
1 in. of fresh water = 25.4 mm water
= 2.54 gm/cm^2
1 in. of mercury = 25.4 mm Hg
= 34.54 gm/cm^2

Length

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

Area

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

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

Volume and capacity

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

Weight

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

Weights of fresh water

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

Pressure

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

[Metric units to U.S. units]

Length

1 cm	=0.394 in.
1 meter	=39.37 in.
	=3.28 ft
1 kilometer	=0.621 mi

Area

1 cm^2	=0.155 sq in.
1 m^2	=10.76 sq ft
1 sq km	=0.386 sq mi

Volume and capacity

1 cc or ml	=0.061 cu in.
1 cu m	=35.31 cu ft
1 liter	=61.02 cu in.
	=0.035 cu ft
	=33.81 fl oz
	=1.057 quarts

Weight

1 gram	=0.035 oz
1 kg	=35.27 oz
	=2.205 lb

Pressure

1 gm/cm^2	=0.394 inch of fresh water
1 kg/cm^2	=14.22 psi
	=32.8 feet of fresh water
	=28.96 inches of mercury
1 cm Hg	=0.193 psi
	=0.446 foot of fresh water
	=0.394 inch of mercury
1 cm of fresh water	=0.394 inch of fresh water

TEMPERATURE CONVERSIONS

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

$$°C=\frac{5}{9}\times(°F-32)$$

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

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

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

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

APPENDIX F

DIVING EQUIPMENT CHECKLIST

SELF-CONTAINED DIVING EQUIPMENT LIST

The following is a list of equipment that should be available for all research diving operations where SCUBA is used. Each member of the diving team should be outfitted with most items; however, some items (indicated by**) need only be carried by one member of the team or in a team equipment chest. Optional items are indicated by a single asterisk (*). Additional items may be included based on mission requirements or personal preference.

Bag, equipment
Bag, net
Belt, weight
Cement, neoprene wet suit
Chest, equipment
Compass, underwater
Compressor, high-pressure air **
Cylinders, CO_2 lifejacket (2) (if required) **
Exposure suit (type depends on mission requirements)
- Foamed-neoprene, wet-type
  - Boots
  - Hooded undervest *
  - Mitts
  - Pants
  - Shirt
- Variable-volume type
  - Hose assembly and adaptor for SCUBA regulator
  - Mitts
  - Suit
  - Underwear

Fins, swim
Flag, diver's **
Flare, distress, day and night
Float assembly, flat **
Gauge, depth
Gauge, pressure, cylinder **
Inhalator, oxygen **
Kit, air analysis, field **
Kit, first aid, individual (contents may vary with geographic location)**
- Alcohol for ear rinse (70 percent solution) (2 oz)
- Ammonia solution
- Antiseptic spray
- Band aids (10)
- Butterfly closures (10)

- Compresses (2)
- Cotton Swabs (10)
- Forceps
- Razor blade or scalpel
- Scissors
- Snakebite kit
- Splint, inflatable *
- Surgical soap (2 oz)
- Tape, adhesive, 1 in. wide
- Triangular bandage (1)

Kit, tool and repair
- Disk, safety
- Knife, small
- Lubricant, silicone
- O-rings, cylinder orifice (3)
- Patches, lifejacket
- Screwdriver
- Tape, plastic, black
- Wrench, adjustable, 6 in.

Lifejacket, gas inflatable, yoke type (CO_2 or air)
Light, underwater *
Line, buddy, 6 ft **
Line, safety, 200 ft **
Log book, diver's individual
Log book, field
Manual, diving **
Mask
Meter, decompression *
Notebook and pencil
Observation board *
Reel, safety line **
SCUBA, open circuit
- Auxiliary emergency SCUBA assembly *
- Auxiliary second-stage assembly
- Cylinders (2)
- Demand regulator
- Gauge, submersible, pressure
- Harness assembly

Slate (with lanyard and pencil)
Snorkel
Suit, swim
Tables, US Navy standard air decompression and repetitive dive
Towels (2)
Watch, underwater
Weights, lead, 3 lb (7)

SURFACE-SUPPLIED DIVING EQUIPMENT LIST

The following is a list of equipment that should be available for research diving operations where surface-supplied diving is required:

Asterisk indications are

- * Optional.
- ** A lightweight helmet may be substituted for one mask.
- *** A low-pressure compressor, 50-125 ft^3/min, and receiver tank, may be substituted for these items; one or more 240 or 300 ft^3 cylinders and fittings should be retained for emergency supply.
- **** A hot water suit system including suits, gloves, boots, hose, heater, manifold unit, fuel and fuel regulators may be substituted for these items.

Antifogging compound
Backpack, emergency air (cylinder, regulator, and harness)
Bag, diver's tool
Batteries, for underwater light (10)
Belt, diver's weight, 35 lb
Belt, diver's weight, 25 lb
Binder, cylinder (2) ***
Cement, suit
Chest, equipment (3)
Communications unit
Compressor, high-pressure air ***
Connector, marsh-marine (2 pr)
Coupling, air to oxygen (6) ***
Coupling, air hose, double male (6)
Coupling, air hose, female, 9/16 in., 18, oxygen, reusable (16)
Coupling, oxygen tee (6) or manifold, oxygen, 5 outlet (2) ***
Cuffs, diver's dress (1 pr)
Cylinders, high pressure, 300 ft^3 (8) ***
Dress, variable-volume, medium size****
Dress, variable-volume, large size****
Filler assembly, cylinder ***
Flag, diver's
Gasket, face
Gloves (2 pr) ***
Harness, diver's safety (2)
Hose assemblies (air hose and communications line taped and fitted with compatible fittings and connectors)--100 ft, 150 ft, 300 ft.

Hose assembly, air, 3 ft (2)
Hose assembly, suit inflator (2) ****
Kit, air analysis
Kit, first aid (contents may vary with geographic location)
- Alcohol for ear rinse (70% solution) (2 oz)
- Ammonia solution
- Antiseptic spray
- Band aids (10)
- Butterfly closures (10)
- Compresses (2)
- Cotton swabs (10)
- Forceps
- Razor blade or scalpel
- Scissors
- Snakebite kit
- Splint, inflatable *
- Surgical soap (2 oz)
- Tape, adhesive, 1 in. wide
- Triangular bandage (1)

Kit, tool and repair
- Assorted open-end wrenches
- Knife
- Pliers, wire cutter
- Tape, teflon
- Tape, duct
- Tape, black
- Screwdriver
- Vise grips
- Wrench, adjustable, 12 in.
- Wrench, adjustable, 10 in.
- Wrench, adjustable, 8 in.

Knife, diver's (2)
Light, underwater
Line, descending, 200 ft
Line, distance 60 ft
Log, field (100 sheets)
Lubricant, zipper
Manifold, emergency air, diver's
Manual, diving
Mask, free-flow/demand (2) **
Notebook and pencil (2)
Overboots
Panel, air control
Pigtails, high-pressure oxygen (6) ***

Protector, helmet, head
Rack, cylinder, four (2) ***
Shoes, diver, lightweight (1 pr)
Socks, wool, large (2)
Spray, silicone (2)
Stopwatch (2)
Suit, swim
Tables, US Navy standard air decompression and repetitive dive
Underwear (2)
Weight, 25 lb
Weights, leg, 5 lb (2)