CHAPTER 1

History of Diving

1-1 INTRODUCTION

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

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

1-1.3 Role of the U.S. Navy. The U.S. Navy is a leader in the development of modern diving and underwater operations. The general requirements of national defense and the specific requirements of underwater reconnaissance, demolition, ordnance disposal, construction, ship maintenance, search, rescue and salvage operations repeatedly give impetus to training and development. Navy diving is no longer limited to tactical combat operations, wartime salvage, and submarine sinkings. Fleet diving has become increasingly important and diversified since World War II. A major part of the diving mission is inspecting and repairing naval vessels to minimize downtime and the need for dry-docking. Other aspects of fleet diving include recovering practice and research torpedoes, installing and repairing underwater electronic arrays, underwater construction, and locating and recovering downed aircraft.

1-2 SURFACE-SUPPLIED AIR DIVING

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

Diving, as a profession, can be traced back more than 5,000 years. Early divers confined their efforts to waters less than 100 feet deep, performing salvage work and harvesting food, sponges, coral, and mother-of-pearl. A Greek historian, Herodotus, recorded the story of a diver named Scyllis, who was employed by the Persian King Xerxes to recover sunken treasure in the fifth century B.C.

From the earliest times, divers were active in military operations. Their missions included cutting anchor cables to set enemy ships adrift, boring or punching holes in the bottoms of ships, and building harbor defenses at home while attempting to destroy those of the enemy abroad. Alexander the Great sent divers down to remove obstacles in the harbor of the city of Tyre, in what is now Lebanon, which he had taken under siege in 332 B.C.

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

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

At first glance, it seemed logical that a longer breathing tube was the only requirement for extending a diver's range. In fact, a number of early designs used leather hoods with long flexible tubes supported at the surface by floats. There is no record, however, that any of these devices were actually constructed or tested. The result may well have been the drowning of the diver. At a depth of 3 feet, it is nearly impossible to breathe through a tube using only the body's natural respiratory ability, as the weight of the water exerts a total force of almost 200 pounds on the diver's chest. This force increases steadily with depth and is one of the most important factors in diving. Successful diving operations require that the pressure be overcome or eliminated. Throughout history, imaginative devices were designed to overcome this problem, many by some of the greatest minds of the time. At first, the problem of pressure underwater was not fully understood and the designs were impractical.

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

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

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

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

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

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

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

In 1690, the English astronomer Edmund Halley developed a diving bell in which the atmosphere was replenished by sending weighted barrels of air down from the surface (Figure 1-3). In an early demonstration of his system, he and four companions remained at 60 feet in the Thames River for almost 1½ hours. Nearly 26 years later, Halley spent more than 4 hours at 66 feet using an improved version of his bell.

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

1-2.4.1 **Lethbridge’s Diving Dress.** In 1715, Englishman John Lethbridge developed a one-man, completely enclosed diving dress (Figure 1-4). The Lethbridge equipment was a reinforced, leather-covered barrel of air, equipped with a glass porthole for viewing and two arm holes with watertight sleeves. Wearing this gear, the occupant could accomplish useful work. This apparatus was lowered from a ship and maneuvered in the same manner as a diving bell.

Lethbridge was quite successful with his invention and participated in salvaging a number of European wrecks. In a letter to the editor of a popular magazine in 1749, the inventor noted that his normal operating depth was 10 fathoms (60 feet),

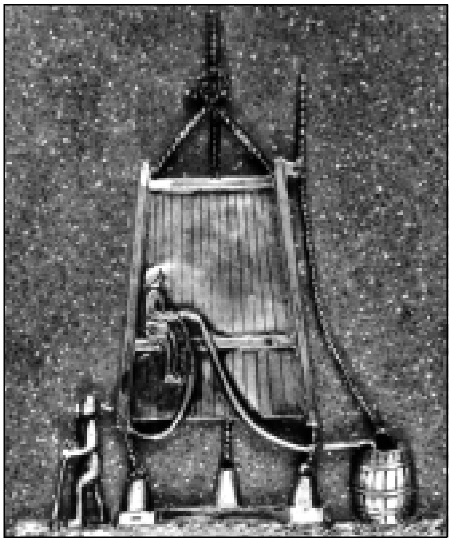

Figure 1-3. Engraving of Halley's Diving Bell.

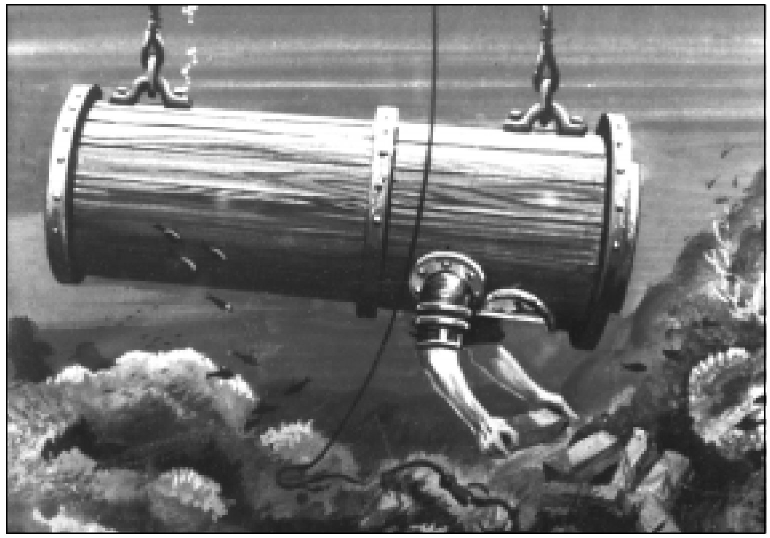

Figure 1-4. Lethbridge's Diving Suit.

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

Several designs similar to Lethbridge's were used in succeeding years. However, all had the same basic limitation as the diving bell—the diver had little freedom because there was no practical way to continually supply him with air. A true technological breakthrough occurred at the turn of the 19th century when a hand-operated pump capable of delivering air under pressure was developed.

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

1-2.4.3 **Siebe's Improved Diving Dress.** Credit for developing the first practical diving dress has been given to Augustus Siebe. Siebe's initial contribution to diving was a modification of the Deane outfit. Siebe sealed the helmet to the dress at the collar by using a short, waist-length waterproof suit and added an exhaust valve to the system (Figure 1-5). Known as Siebe's Improved Diving Dress, this apparatus is the direct ancestor of the MK V standard deep-sea diving dress.

1-2.4.4 **Salvage of the HMS *Royal George*.** By 1840, several types of diving dress were being used in actual diving operations. At that time, a unit of the British Royal Engineers was engaged in removing the remains of the sunken warship, HMS *Royal George*. The warship was fouling a major fleet anchorage just outside Portsmouth, England. Colonel William Pasley, the officer in charge, decided that his operation was an ideal opportunity to formally test and evaluate the various types of apparatus. Wary of the Deane apparatus because of the possibility of helmet flooding, he formally recommended that the Siebe dress be adopted for future operations.

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

When Pasley's project was completed, an official government historian noted that "of the seasoned divers, not a man escaped the repeated attacks of rheumatism and cold." The divers had been working for 6 or 7 hours a day, much of it spent at depths of 60 to 70 feet. Pasley and his men did not realize the implications of the observation. What appeared to be rheumatism was instead a symptom of a far more serious physiological problem that, within a few years, was to become of great importance to the diving profession.

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

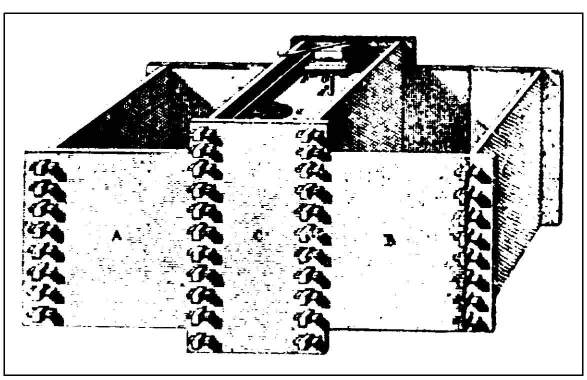

Figure 1-6. French Caisson. This caisson could be floated over the work site and lowered to the bottom by flooding the side tanks.

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

1-2.6 Physiological Discoveries.

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

As caisson work extended to larger projects and to greater operating pressures, the physiological problems increased in number and severity. Fatalities occurred with alarming frequency. The malady was called, logically enough, caisson disease. However, workers on the Brooklyn Bridge project in New York gave the sickness a more descriptive name that has remained—the “bends.”

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

1-2.6.1.1 ***Cause of Decompression Sickness.*** The actual cause of caisson disease was first clinically described in 1878 by a French physiologist, Paul Bert. In studying the effect of pressure on human physiology, Bert determined that breathing air under pressure forced quantities of nitrogen into solution in the blood and tissues of the body. As long as the pressure remained, the gas was held in solution. When the pressure was quickly released, as it was when a worker left the caisson, the nitrogen returned to a gaseous state too rapidly to pass out of the body in a natural manner. Gas bubbles formed throughout the body, causing the wide range of symptoms associated with the disease. Paralysis or death could occur if the flow of blood to a vital organ was blocked by the bubbles.

1-2.6.1.2 ***Prevention and Treatment of Decompression Sickness.*** Bert recommended that caisson workers gradually decompress and divers return to the surface slowly. His studies led to an immediate improvement for the caisson workers when they discovered their pain could be relieved by returning to the pressure of the caisson as soon as the symptom appeared.

Within a few years, specially designed recompression chambers were being placed at job sites to provide a more controlled situation for handling the bends. The pressure in the chambers could be increased or decreased as needed for an individual worker. One of the first successful uses of a recompression chamber was in 1879 during the construction of a subway tunnel under the Hudson River between New

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

Bert's recommendation that divers ascend gradually and steadily was not a complete success, however; some divers continued to suffer from the bends. The general thought at the time was that divers had reached the practical limits of the art and that 120 feet was about as deep as anyone could work. This was because of the repeated incidence of the bends and diver inefficiency beyond that depth. Occasionally, divers would lose consciousness while working at 120 feet.

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

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

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

1-2.6.3 **Nitrogen Narcosis.** Divers soon were moving into deeper water and another unexplained malady began to appear. The diver would appear intoxicated, sometimes feeling euphoric and frequently losing judgment to the point of forgetting the dive's purpose. In the 1930s this "rapture of the deep" was linked to nitrogen in the air breathed under higher pressures. Known as nitrogen narcosis, this condition occurred because nitrogen has anesthetic properties that become progressively more severe with increasing air pressure. To avoid the problem, special breathing mixtures such as helium-oxygen were developed for deep diving (see section 1-4, Mixed-Gas Diving).

Figure 1-7. Armored Diving Suit.

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

The utility of most armored suits was questionable. They were too clumsy for the diver to be able to accomplish much work and too complicated to provide protection from extreme pressure. The maximum anticipated depth of the various suits developed in the 1930s was 700 feet, but was never reached in actual diving. More recent pursuits in the area of armored suits, now called one-atmosphere diving suits, have demonstrated their capability for specialized underwater tasks to 2,000 feet of saltwater (fsw).

1-2.8 **MK V Deep-Sea Diving Dress.** By 1905, the Bureau of Construction and Repair had designed the MK V Diving Helmet which seemed to address many of the problems encountered in diving. This deep-sea outfit was designed for extensive, rugged diving work and provided the diver maximum physical protection and some maneuverability.

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

By 1916, several improvements had been made to the helmet, including a rudimentary communications system via a telephone cable and a regulating valve operated by an interior push button. The regulating valve allowed some control of the atmospheric pressure. A supplementary relief valve, known as the spitcock, was added to the left side of the helmet. A safety catch was also incorporated to keep the helmet attached to the breast plate. The exhaust valve and the communications system were improved by 1927, and the weight of the helmet was decreased to be more comfortable for the diver.

After 1927, the MK V changed very little. It remained basically the same helmet used in salvage operations of the USS S-51 and USS S-4 in the mid-1920s. With its associated deep-sea dress and umbilical, the MK V was used for all submarine rescue and salvage work undertaken in peacetime and practically all salvage work undertaken during World War II. The MK V Diving Helmet was the standard U.S. Navy diving equipment until succeeded by the MK 12 Surface-Supplied Diving System (SSDS) in February 1980 (see Figure 1-8). The MK 12 was replaced by the MK 21 in December 1993.

1-3 SCUBA DIVING

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

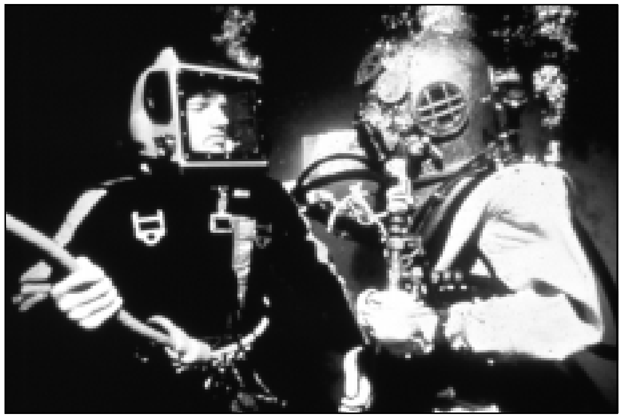

Figure 1-8. MK 12 and MK V.

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

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

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

1-3.1.1 **Rouquayrol's Demand Regulator.** The first and highly necessary component of an open-circuit apparatus was a demand regulator. Designed early in 1866 and patented by Benoist Rouquayrol, the regulator adjusted the flow of air from the tank to meet the diver's breathing and pressure requirements. However, because cylinders strong enough to contain air at high pressure could not be built at the time, Rouquayrol adapted his regulator to surface-supplied diving equipment and the technology turned toward closed-circuit designs. The application of Rouquayrol's concept of a demand regulator to a successful open-circuit scuba was to wait more than 60 years.

1-3.1.2 **LePrieur's Open-Circuit Scuba Design.** The thread of open-circuit development was picked up in 1933. Commander LePrieur, a French naval officer, constructed an open-circuit scuba using a tank of compressed air. However, LePrieur did not include a demand regulator in his design and, the diver's main effort was diverted to the constant manual control of his air supply. The lack of a demand regulator, coupled with extremely short endurance, severely limited the practical use of LePrieur's apparatus.

1-3.1.3 **Cousteau and Gagnan's Aqua-Lung.** At the same time that actual combat operations were being carried out with closed-circuit apparatus, two Frenchmen achieved a significant breakthrough in open-circuit scuba design. Working in a small Mediterranean village, under the difficult and restrictive conditions of German-occupied France, Jacques-Yves Cousteau and Emile Gagnan combined an improved demand regulator with high-pressure air tanks to create the first truly efficient and safe open-circuit scuba, known as the Aqua-Lung. Cousteau and his companions brought the Aqua-Lung to a high state of development as they explored and photographed wrecks, developing new diving techniques and testing their equipment.

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

1-3.1.4 **Impact of Scuba on Diving.** The underwater freedom brought about by the development of scuba led to a rapid growth of interest in diving. Sport diving has become very popular, but science and commerce have also benefited. Biologists, geologists and archaeologists have all gone underwater, seeking new clues to the origins and behavior of the earth, man and civilization as a whole. An entire industry has grown around commercial diving, with the major portion of activity in offshore petroleum production.

After World War II, the art and science of diving progressed rapidly, with emphasis placed on improving existing diving techniques, creating new methods, and developing the equipment required to serve these methods. A complete generation of new and sophisticated equipment took form, with substantial improvements being made in both open and closed-circuit apparatus. However, the most significant aspect of this technological expansion has been the closely linked development of saturation diving techniques and deep diving systems.

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

1-3.2.1 **Fleuss' Closed-Circuit Scuba.** Henry A. Fleuss developed the first commercially practical closed-circuit scuba between 1876 and 1878 (Figure 1-9). The Fleuss device consisted of a watertight rubber face mask and a breathing bag connected to a copper tank of 100 percent oxygen charged to 450 psi. By using oxygen instead of compressed air as the breathing medium, Fleuss eliminated the need for high-strength tanks. In early models of this apparatus, the diver controlled the makeup feed of fresh oxygen with a hand valve.

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

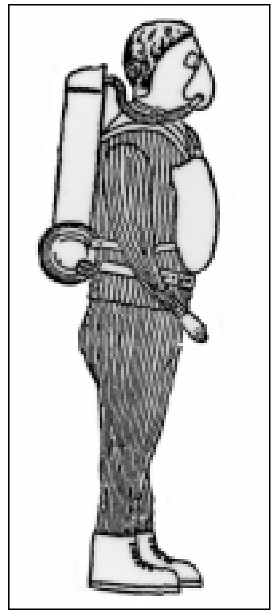

Figure 1-9. Fleuss Apparatus.

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

1-3.2.2 **Modern Closed-Circuit Systems.** As development of the closed-circuit design continued, the Fleuss equipment was improved by adding a demand regulator and tanks capable of holding oxygen at more than 2,000 psi. By World War I, the Fleuss scuba (with modifications) was the basis for submarine escape equipment used in the Royal Navy. In World War II, closed-circuit units were widely used for combat diving operations (see paragraph 1-3.5.2).

Some modern closed-circuit systems employ a mixed gas for breathing and electronically senses and controls oxygen concentration. This type of apparatus retains the bubble-free characteristics of 100-percent oxygen recirculators while significantly improving depth capability.

1-3.3 Hazards of Using Oxygen in Scuba.

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

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

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

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

1-3.4 Semiclosed-Circuit Scuba. The semiclosed-circuit scuba combines features of the open and closed-circuit systems. Using a mixture of gases for breathing, the apparatus recycles the gas through a carbon dioxide removal canister and continually adds a small amount of oxygen-rich mixed gas to the system from a supply cylinder. The supply gas flow is preset to satisfy the body's oxygen demand; an equal amount of the recirculating mixed-gas stream is continually exhausted to the water. Because the quantity of makeup gas is constant regardless of depth, the semiclosed-circuit scuba provides significantly greater endurance than open-circuit systems in deep diving.

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

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

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

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

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

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

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

Figure 1-10. Original Davis Submerged Escape Apparatus.

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

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

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

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

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

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

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

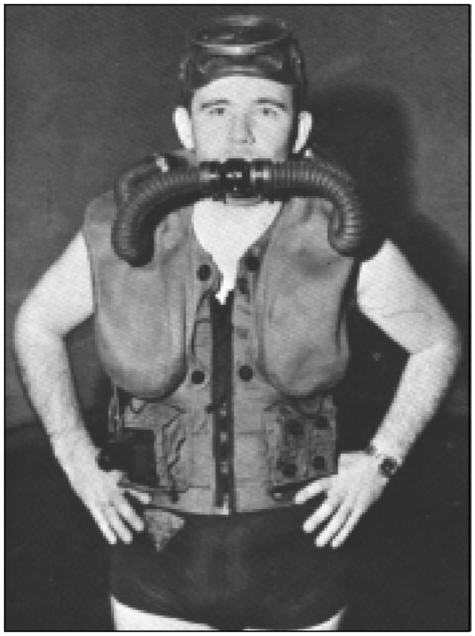

Figure 1-12. Emerson-Lambertsen Oxygen Rebreather.

Figure 1-13. Draeger LAR V UBA.

combat swimmers. SEAL team members are trained to operate in all of these environments. They qualify as parachutists, learn to handle a range of weapons, receive intensive training in hand-to-hand combat, and are expert in scuba and other swimming and diving techniques. In Vietnam, SEALs were deployed in special counter-insurgency and guerrilla warfare operations. The SEALs also participated in the space program by securing flotation collars to returned space capsules and assisting astronauts during the helicopter pickup.

1-3.5.3 **Underwater Demolition.** The Navy's Underwater Demolition Teams (UDTs) were created when bomb disposal experts and Seabees (combat engineers) teamed together in 1943 to devise methods for removing obstacles that the Germans were placing off the beaches of France. The first UDT combat mission was a daylight reconnaissance and demolition project off the beaches of Saipan in June 1944. In March of 1945, preparing for the invasion of Okinawa, one underwater demolition team achieved the exceptional record of removing 1,200 underwater obstacles in 2 days, under heavy fire, without a single casualty.

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

Through the years since, the mission and importance of the UDT has grown. In the Korean Conflict, during the period of strategic withdrawal, the UDT destroyed an entire port complex to keep it from the enemy. The UDTs have since been incorporated into the Navy Seal Teams.

1-4 MIXED-GAS DIVING

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

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

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

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

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

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

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

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

1-4.1 Nonsaturation Diving.

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

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

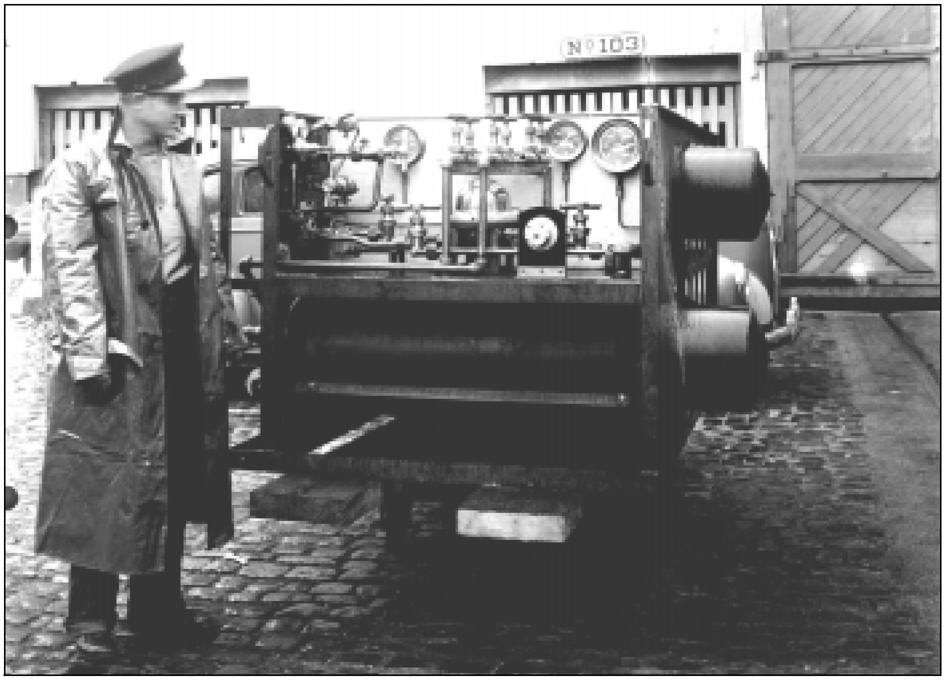

Figure 1-14. Helium-Oxygen Diving Manifold.

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

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

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

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

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

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

Figure 1-15. MK V MOD 1 Helmet.

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

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

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

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

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

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

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

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

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

Figure 1-16. MK 1 MOD 0 Diving Outfit

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

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

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

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

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

1-4.3 Saturation Diving.

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

1-4.3.1 Advantages of Saturation Diving.

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

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

If a diver could remain under pressure for the entire period of the required task, the diver would face a lengthy decompression only when completing the project. For a 40-hour task at 200 fsw, a saturated diver would spend 5 days at bottom pressure and 2 days in decompression, as opposed to spending 40 days making 1-hour dives with long decompression periods using conventional methods.

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

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

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

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

- The first practical open-sea demonstrations of saturation diving were undertaken in September 1962 by Edward A. Link and Captain Jacques-Yves Cousteau.
- Link's Man-in-the-Sea program had one man breathing helium-oxygen at 200 fsw for 24 hours in a specially designed diving system.
- Cousteau placed two men in a gas-filled, pressure-balanced underwater habitat at 33 fsw where they stayed for 169 hours, moving freely in and out of their deep-house.
- Cousteau's Conshelf One supported six men breathing nitrogen-oxygen at 35 fsw for 7 days.
- In 1964, Link and Lambertsen conducted a 2-day exposure of two men at 430 fsw.
- Cousteau's Conshelf Two experiment maintained a group of seven men for 30 days at 36 fsw and 90 fsw with excursion dives to 330 fsw.

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

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

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

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

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

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

Figure 1-17. Sealab II.

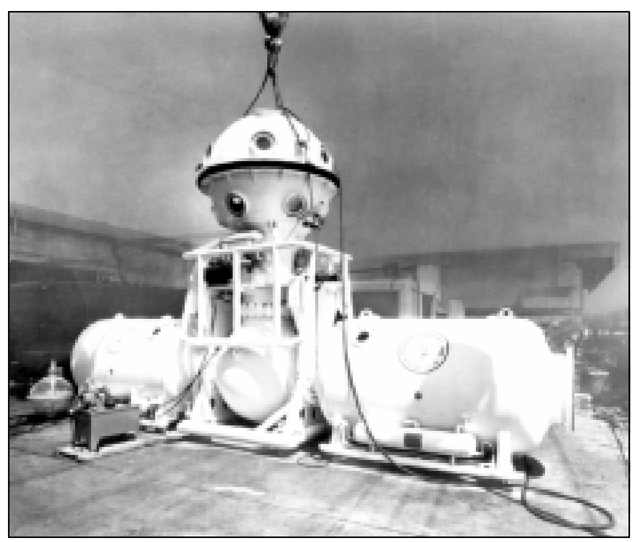

Figure 1-18. U.S. Navy's First DDS, SDS-450.

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

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

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

1-4.4 Deep Diving Systems (DDS). Experiments in saturation technique required substantial surface support as well as extensive underwater equipment. DDS are a substantial improvement over previous methods of accomplishing deep undersea work. The DDS is readily adaptable to saturation techniques and safely maintains the saturated diver under pressure in a dry environment. Whether employed for saturation or nonsaturation diving, the Deep Diving System totally eliminates long decompression periods in the water where the diver is subjected to extended environmental stress. The diver only remains in the sea for the time spent on a given task. Additional benefits derived from use of the DDS include eliminating the need for underwater habitats and increasing operational flexibility for the surface-support ship.

The Deep Diving System consists of a Deck Decompression Chamber (DDC) mounted on a surface-support ship. A Personnel Transfer Capsule (PTC) is mated to the DDC, and the combination is pressurized to a storage depth. Two or more divers enter the PTC, which is unmated and lowered to the working depth. The interior of the capsule is pressurized to equal the pressure at depth, a hatch is opened, and one or more divers swim out to accomplish their work. The divers can use a self-contained breathing apparatus with a safety tether to the capsule, or employ a mask and an umbilical that provides breathing gas and communications. Upon completing the task, the divers enters the capsule, close the hatch and return to the support ship with the interior of the PTC still at the working pressure. The capsule is hoisted aboard and mated to the pressurized DDC. The divers enter the larger, more comfortable DDC via an entry lock. They remain in the DDC until they must return to the undersea job site. Decompression is carried out comfortably and safely on the support ship.

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

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

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

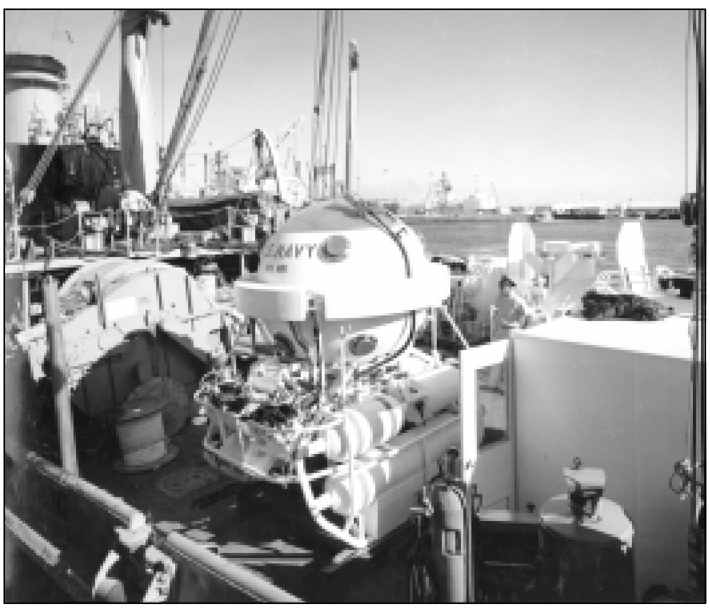

Figure 1-19. DDS MK 1 Personnel Transfer Capsule.

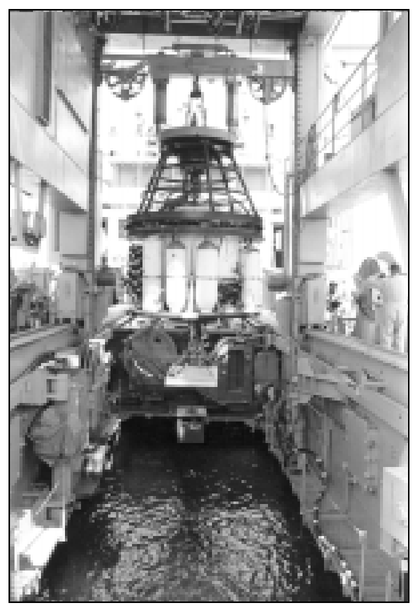

Figure 1-20. PTC Handling System, *Elk River*.

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

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

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

1-5 SUBMARINE SALVAGE AND RESCUE

At the beginning of the 20th century, all major navies turned their attention toward developing a weapon of immense potential—the military submarine. The highly effective use of the submarine by the German Navy in World War I heightened this interest and an emphasis was placed on the submarine that continues today.

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

Until 1912, U.S. Navy divers rarely went below 60 fsw. In that year, Chief Gunner George D. Stillson set up a program to test Haldane's diving tables and methods of stage decompression. A companion goal of the program was to improve Navy diving equipment. Throughout a 3-year period, first diving in tanks ashore and then in open water in Long Island Sound from the USS *Walkie*, the Navy divers went progressively deeper, eventually reaching 274 fsw.

1-5.1 USS F-4. The experience gained in Stillson's program was put to dramatic use in 1915 when the submarine USS F-4 sank near Honolulu, Hawaii. Twenty-one men lost their lives in the accident and the Navy lost its first boat in 15 years of submarine operations. Navy divers salvaged the submarine and recovered the bodies of the crew. The salvage effort incorporated many new techniques, such as using lifting pontoons. What was most remarkable, however, was that the divers completed a major salvage effort working at the extreme depth of 304 fsw, using air as a breathing mixture. The decompression requirements limited bottom time for each dive to about 10 minutes. Even for such a limited time, nitrogen narcosis made it difficult for the divers to concentrate on their work.

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

The physiological problems encountered in the salvage of the USS F-4 clearly demonstrated the limitations of breathing air during deep dives. Continuing concern that submarine rescue and salvage would be required at great depth focused Navy attention on the need for a new diver breathing medium.

1-5.2 **USS S-51.** In September of 1925, the USS S-51 submarine was rammed by a passenger liner and sunk in 132 fsw off Block Island, Rhode Island. Public pressure to raise the submarine and recover the bodies of the crew was intense. Navy diving was put in sharp focus, realizing it had only 20 divers who were qualified to go deeper than 90 fsw. Diver training programs had been cut at the end of World War I and the school had not been reinstituted.

Salvage of the USS S-51 covered a 10-month span of difficult and hazardous diving, and a special diver training course was made part of the operation. The submarine was finally raised and towed to the Brooklyn Navy Yard in New York.

Interest in diving was high once again and the Naval School, Diving and Salvage, was reestablished at the Washington Navy Yard in 1927. At the same time, the Navy brought together its existing diving technology and experimental work by shifting the Experimental Diving Unit (EDU), which had been working with the Bureau of Mines in Pennsylvania, to the Navy Yard as well. In the following years, EDU developed the U.S. Navy Air Decompression Tables, which have become the accepted world standard and continued developmental work in helium-oxygen breathing mixtures for deeper diving.

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

1-5.3 **USS S-4.** In 1927, the Navy lost the submarine USS S-4 in a collision with the Coast Guard cutter USS *Paulding*. The first divers to reach the submarine in 102 fsw, 22 hours after the sinking, exchanged signals with the men trapped inside. The submarine had a hull fitting designed to take an air hose from the surface, but what had looked feasible in theory proved too difficult in reality. With stormy seas causing repeated delays, the divers could not make the hose connection until it was too late. All of the men aboard the USS S-4 had died. Even had the hose connection been made in time, rescuing the crew would have posed a significant problem.

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

1-5.4 **USS *Squalus*.** The Navy pushed for development of a rescue chamber that was essentially a diving bell with special fittings for connection to a submarine deck hatch. The apparatus, called the McCann-Erickson Rescue Chamber, was proven in 1939 when the USS *Squalus*, carrying a crew of 50, sank in 243 fsw. The rescue chamber made four trips and safely brought 33 men to the surface. (The rest of the crew, trapped in the flooded after-section of the submarine, had perished in the sinking.)

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

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

1-5.5 **USS *Thresher*.** Just as the loss of the USS F-4, USS S-51, USS S-4 and the sinking of the USS *Squalus* caused an increased concern in Navy diving in the 1920s and 1930s, a submarine disaster of major proportions had a profound effect on the development of new diving equipment and techniques in the postwar period. This was the loss of the nuclear attack submarine USS *Thresher* and all her crew in April 1963. The submarine sank in 8,400 fsw, a depth beyond the survival limit of the hull and far beyond the capability of any existing rescue apparatus.

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

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

1-5.6 **Deep Submergence Systems Project.** Direct action on the recommendations of the DSRG came with the formation of the Deep Submergence Systems Project (DSSP) in 1964 and an expanded interest regarding diving and undersea activity throughout the Navy.

Submarine rescue capabilities have been substantially improved with the development of the Deep Submergence Rescue Vehicle (DSRV) which became operational in 1972. This deep-diving craft is air-transportable, highly instrumented, and capable of diving to 5,000 fsw and rescues to 2,500 fsw.

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

1-6 SALVAGE DIVING

1-6.1 World War II Era.

1-6.1.1 **Pearl Harbor.** Navy divers were plunged into the war with the Japanese raid on Pearl Harbor. The raid began at 0755 on 7 December 1941; by 0915 that same morning, the first salvage teams were cutting through the hull of the overturned battleship USS *Oklahoma* to rescue trapped sailors. Teams of divers worked to recover ammunition from the magazines of sunken ships, to be ready in the event of a second attack.

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

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

1-6.1.2 **USS *Lafayette*.** While divers in the Pacific were hard at work at Pearl Harbor, a major challenge was presented to the divers on the East Coast. The interned French passenger liner *Normandie* (rechristened as the USS *Lafayette*) caught fire alongside New York City's Pier 88. Losing stability from the tons of water poured on the fire, the ship capsized at her berth.

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

1-6.1.3 **Other Diving Missions.** Salvage operations were not the only missions assigned to Navy divers during the war. Many dives were made to inspect sunken enemy ships and to recover materials such as code books or other intelligence items. One Japanese cruiser yielded not only $500,000 in yen, but also provided valuable information concerning plans for the defense of Japan against the anticipated Allied invasion.

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

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

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

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

1-7 OPEN-SEA DEEP DIVING RECORDS

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

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

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

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

1-8 SUMMARY

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

Each person who prepares for a dive has the opportunity and obligation to take along the knowledge of his or her predecessors that was gained through difficult and dangerous experience. The modern diver must have a broad understanding of the physical properties of the undersea environment and a detailed knowledge of his or her own physiology and how it is affected by the environment. Divers must learn to adapt to environmental conditions to successfully carry out their missions.

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

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